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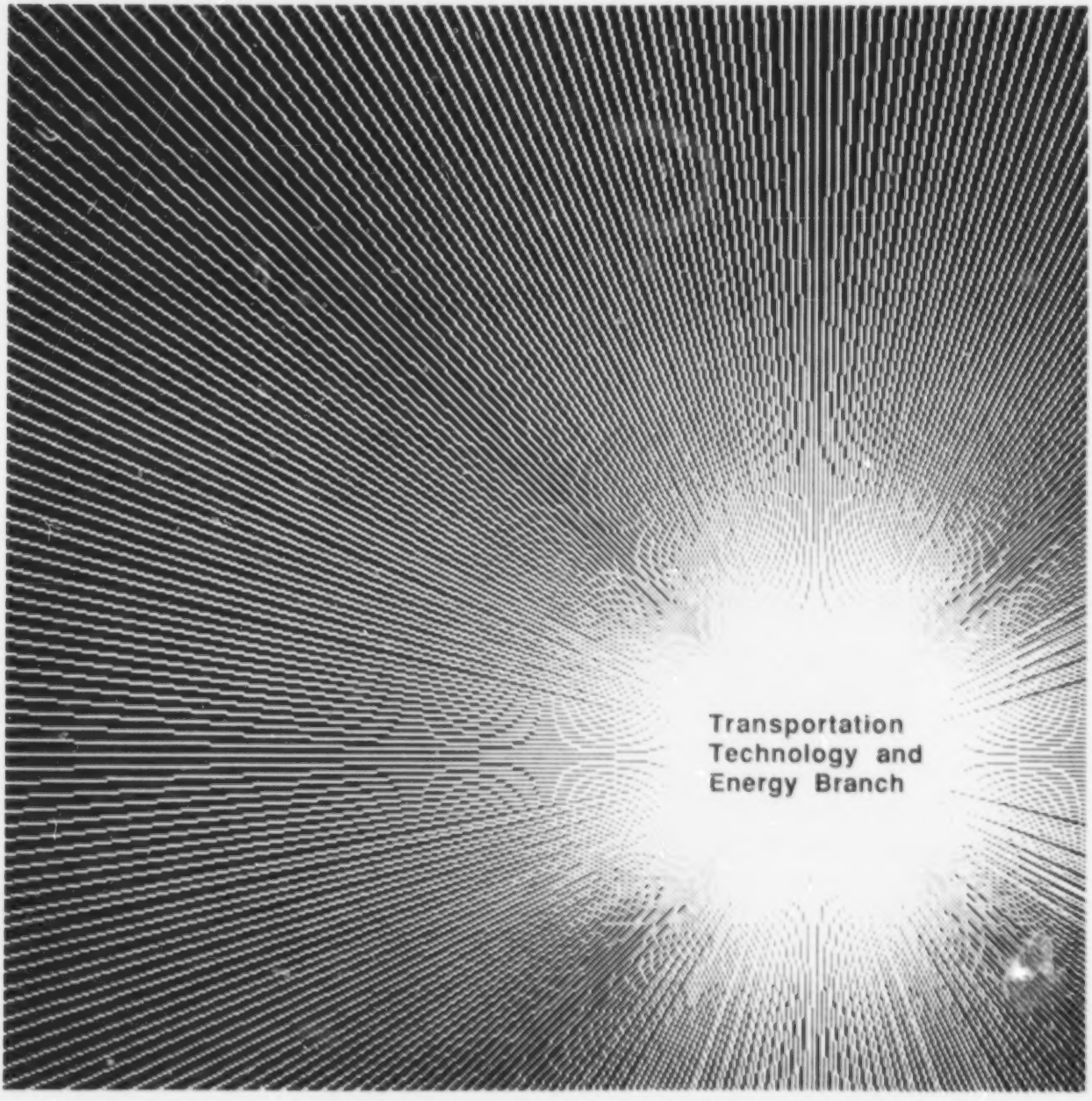

92-01828/

Assessment of a Transportable Mobility Aid in Severe Driving Conditions – An Exploratory Test

CV-90-03

Technical Report Documentation Page

Assessment of a Transportable Mobility Aid in Severe Driving Conditions – An Exploratory Test

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Abstract: A severe driving test was conducted on a vehicle containing a transportable mobility aid (a scooter) with a male anthropomorphic dummy as a rider. A portion of the test was to see if the system behaved in accordance with CSA D409 Standard. The remaining portion of the test was to observe the behavior of the system under high dynamic vehicle induced loading.

The test showed that the base of the scooter met the D409 standard. However, the displacement of the upper portions of the scooter, which are not specified in D409, exceeded the displacements of the base by a large margin. Under high dynamic loading, up to 0.8 g lateral acceleration, the scooter responded with high roll angles and large lateral swaying motions. It was found that these were very sensitive to the manner in which the scooter was secured, and the air pressure in the scooter tires. Loads measured in the restraint system indicated that the restraints were operating well under design limits.

This test was done to provide insight to the Canadian Standards Association committee currently examining the D409 standard regarding securement of this type of mobility aid.

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CONTENT

PAGE

ACKNOWLEDGEMENTS iv

EXECUTIVE SUMMARY v

1/ INTRODUCTION 1

2/ OBJECTIVE 1

3/ TEST PHILOSOPHY AND METHODOLOGY 3

4/ INSTRUMENTATION AND EQUIPMENT 6

5/ TEST PROGRAM 15
- 5.1/ Acceleration, per D409 15
- 5.2/ Braking, per D409 15
- 5.3/ Constant Radius Turn, per D409 15
- 5.4/ Double Lane Change 15
- 5.5/ Spiral 90° Right Turn 15
- 5.6/ Constant Radius Turn 15
- 5.7/ J-turn 17
- 5.8/ Abrupt Braking 17
- 5.9/ Snub Braking 17
- 5.10/ Back-up Braking 17
- 5.11/ Test Matrix 19

6/ OBSERVATIONS AND RESULTS 20
- 6.1/ Acceleration, per D409 20
- 6.2/ Braking, per D409 20
- 6.3/ Constant Radius Turn, per D409 20
- 6.4/ Double Lane Change 25
- 6.5/ Spiral Turn 32
- 6.6/ Constant Radius Turn 32
- 6.7/ J-Turn 38
- 6.8/ Abrupt Braking 38
- 6.9/ Snub Braking 45
- 6.10/ Back-up Braking 45

7/ DISCUSSION 48

8/ CONCLUSIONS 53

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- Barbara Smith of Transportation Development Centre for the procurement of a 50th percentile male anthropomorphic dummy from the Defence and Civil Institute of Environmental Medicine of the Department of National Defence.

This test was conducted by the staff of Vehicle Technology Office, Ontario Ministry of Transportation, at the Commercial Vehicle Test Facility, Centralia, Ontario. The authors acknowledge the contributions of the facility staff for the prompt completion of the test. The test driver was Norman Carlton. Norm drove the entire test and offered valuable information on procedures and data collection. The test director was William Stephenson, P.Eng., who was also responsible for instrumentation and collection of data. Gary Giles installed and calibrated the electronics and assisted in the data collection. Michael Wolkowicz, the facility manager, was responsible for the mechanical outfitting of the vehicle, interior and exterior video recordings of the test, and production of the video film complementary to this report.

Finally, the authors recognize the timely efforts of Teresa Burt and Jennifer Williams to produce this report.

EXECUTIVE SUMMARY

The Canadian Standards Association (CSA) is conducting a scheduled review of the standard CAN3-D409-M84, Motor Vehicles for the Transportation of Physically Disabled Persons. In conjunction with this, CSA is developing further standards related to transportable mobility aids and securement systems. The mobility aid, or "scooter," is a class of vehicle of diverse characteristics. The requirements of D409 and current tie-down systems are probably inappropriate for scooters. While the ultimate scooter and tie- down standard is likely to be based on a crash or sled test, an interim standard based on severe driving conditions is being considered. An exploratory test was therefore conducted by Ontario Ministry of Transportation (MTO) to see what forces and displacements to expect when a typical scooter and tie-down system is subjected to severe driving conditions, and what practical considerations need be examined, if such a test should become part of a standard.

MTO obtained the loan of a vehicle designed for transportation of the disabled, a three-wheeled battery-powered scooter, and a 50th percentile male dummy. The scooter and dummy were installed in the vehicle, and the vehicle, scooter, and tie-down were instrumented.

It was found that, while the base of the scooter remained relatively stationary, the upper portion of the scooter and the dummy moved considerably. During the D409 tests, the scooter seat moved within an envelope 9.7 cm wide and 1.8 cm long, while the base met the strict requirements of D409.

During severe driving tests, the base of the scooter moved up to 2.25 cm laterally, and the upper portion of the seat moved up to 18 cm laterally, from the initial upright position. The scooter's seat displacement and roll angle were very sensitive to the scooter's tire pressure, and preload in the tie-down. A combination of these two variables, within the bounds of this test series, nearly doubled the roll and displacement response of the scooter.

The displacement of the scooter, when secured to manufacturer's recommendations, was linear in both longitudinal and lateral planes, and proportional to longitudinal or lateral acceleration. The scooter and the dummy rolled large amounts under lateral loads. The dummy came very close to the inner wall of the vehicle at various times during tests which gave high lateral acceleration.

The flexibility of the scooter's tires appeared to be the largest contributing factor to roll and dummy lateral displacement. The scooter could probably be as rigid and limited in motion as a standard wheelchair if securement to the floor could be made through floor contact with a structural member of the device.

1/ INTRODUCTION

The Canadian Standards Association (CSA) is conducting a scheduled review of the standard CAN3-D409-M84, Motor Vehicles for the Transportation of Physically Disabled Persons. In conjunction with this, CSA is also developing further standards related to transportable mobility aids and securement systems. The mobility aid, hereinafter referred to as a "scooter," is a class of vehicle of diverse characteristics. It is typically of tricycle design and battery powered. A scooter and seated 50th percentile anthropomorphic dummy is shown in Figure 1. The requirements of D409 and current tie-down systems are probably inappropriate for scooters. While the ultimate scooter and tie-down standard is likely to be based on a crash or sled test, an interim standard based on severe driving conditions is being considered. An exploratory test was therefore conducted to see what forces and displacements to expect when a typical scooter and tie-down system is subjected to severe driving conditions, and what practical considerations need be examined, if such a test should become part of a standard. The test was neither comprehensive, nor a research project. Its function was simply to provide insight to the CSA committee reviewing the D409 standard in its deliberations.

2/ OBJECTIVE

The objective of this test is to determine what severe driving tests can be performed on a vehicle containing a restrained scooter and dummy that will demonstrate the performance of the scooter and tie-down system.

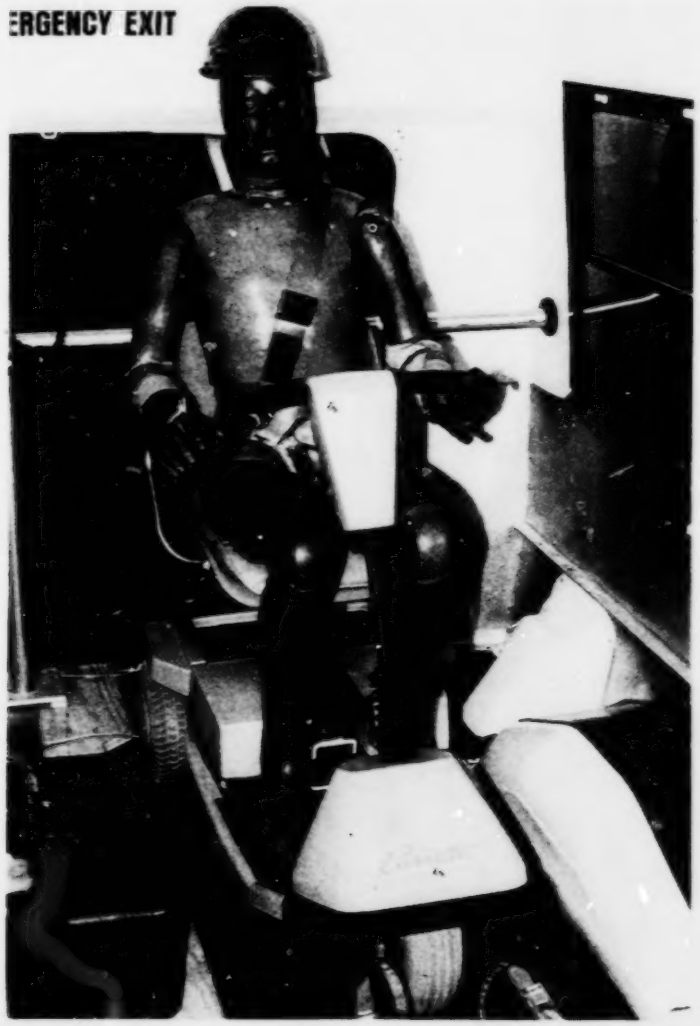


Figure 1/ Scooter, with Anthropomorphic Dummy

3/ TEST PHILOSOPHY AND METHODOLOGY

The exploratory test subjected the vehicle containing the scooter, a typical restraint system, and a dummy seated on the scooter, to the three basic tests described in CSA Standard CAN3-D409-M84, and a series of other tests designed to generate high lateral or longitudinal accelerations within the capability of the vehicle. The test program measured the vehicle accelerations and attitude, the displacements of the scooter, and some forces in the restraint system. The tests did not have a pass/fail criterion. They were designed to demonstrate the responses of a typical scooter relative to the vehicle as a function of vehicle longitudinal or lateral acceleration.

The testing was conducted using a 50th percentile adult male anthropomorphic dummy seated on the scooter as shown in Figure 1. The dummy was secured by a lap belt, and a left shoulder strap, parts of the restraint system. The dummy's wrists were taped to the armrests of the scooter, to represent a rider grasping the handlebars. This may all be seen in Figure 2. The dummy was not instrumented. It was however, the subject of a rear facing video camera to show graphically the motion of the upper torso. This is shown in an accompanying video movie of this test. It is not reported herein as data.

The test program included, as a baseline, the D409 tests of straight-line acceleration, straight-line braking, and steady lateral acceleration. The D409 tests were conducted strictly in accordance with the standard.

The severe driving, or more aggressive tests at higher acceleration levels, were divided into two parts and were as follows:

Lateral Loading
1/ Double lane change
2/ Spiral turn
3/ Constant radius turn
4/ J-turn

Longitudinal Loading
5/ Abrupt braking
6/ Snub braking
7/ Back-up braking

The lateral loading tests were designed to input different types of lateral acceleration to the scooter. These were steady, from the constant radius test; progressive, from the spiral turn; impulsive, from the J-turn; and oscillating, from the double lane change. The longitudinal loading tests were also designed to input different types of longitudinal acceleration to the scooter. These were forward sustained deceleration, from abrupt braking; pulsating deceleration from snub braking; and rearward deceleration,

from braking while driving in reverse. It was felt that these covered the spectrum of lateral and longitudinal inputs that could be provided by a motor vehicle.

In the double lane change, spiral turn, and constant radius turn, test runs were made at progressively increasing speeds, or increasing aggression. This allowed the driver to familiarize himself with the manoeuvre, and allowed the test staff to examine the data at progressive stages for indications of danger. Runs were being conducted close to the limits of vehicle stability. MTO staff always follow the safe and prudent practice of approaching the stability limit in small steps, while monitoring significant vehicle responses to ensure that the test proceeds safely.

Variations in equipment for specific tests included conducting the D409 steady turn and acceleration tests both with and without the dummy. This was done to ascertain the tie-down loads and scooter motion without the influence of the occupant. The severe driving constant radius turn test was also conducted to show the influence of low air pressure in the scooter tires and the effect of not cinching the rear Q-Straint to its recommended load level. This was done to examine the effect of not following recommended practice with the tie-down and scooter maintenance.

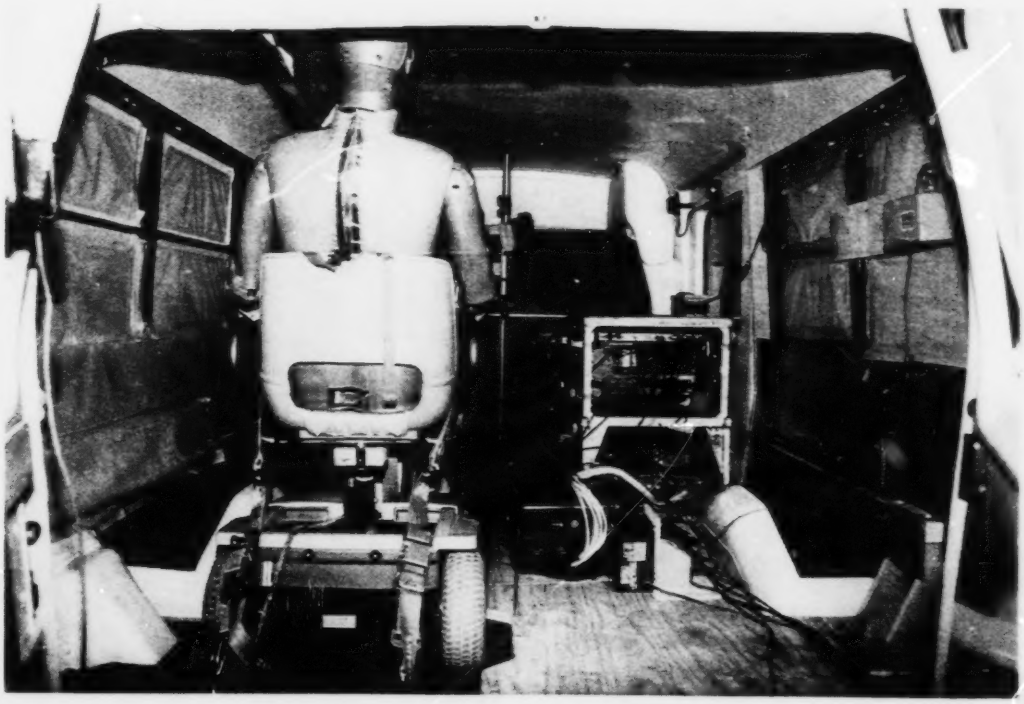


Figure 2/ Securement of Dummy - Rear View Showing

Figure 2/ Securement of Dummy - Side Elevation

4/ INSTRUMENTATION AND EQUIPMENT

The vehicle for the test was provided by Girardin Corporation. It was a standard 1990 Ford chassis with a custom body by Girardin as shown in Figure 3. A Q-Straint tie-down system for the scooter was provided, with lap belt and shoulder harness. In addition, Girardin provided several pieces of hardware for rework as transducers to measure loads in the harness. Finally, Girardin provided the test staff with directions on proper assembly, securement, and use of the restraint system.

Figure 3/ Ford/Girardin Vehicle Used in Test

The scooter was provided by the Research and Development Section of Everest & Jennings Canadian Ltd. The scooter was a battery-powered "Carrette" "Freedom Machine" with pneumatic tires, and rear wheel drive, as shown in Figure 1. The specific unit supplied was from Everest and Jennings R&D inventory, used by R&D for work in the plant. The scooter offered two forward tie-down points near the front spindle and two rear tie-down points at the seat. Everest & Jennings, in consultation with MTO, decided to use the armrest frame for tie-down due to its location and anchoring ability, rather than the seat tie-down points. The scooter had an armrest that could be raised to facilitate mounting and dismounting by the rider. This was secured by MTO with the use of a blocking device at Everest and Jennings's direction.

The dummy used as a rider for the scooter was a 50th percentile male anthropomorphic dummy weighing approximately 72.7 kg, seen in Figures 1 and 2. It had flexible locking joints and was not instrumented. The dummy was obtained for this test by Transportation Development Center of Transport Canada from Defence and Civil Institute of Environmental Medicine, Department of National Defence.

MTO staff assembled the hardware and installed the scooter and restraint system in accordance with recommended industry procedure, and in consultation with the suppliers and manufacturers.

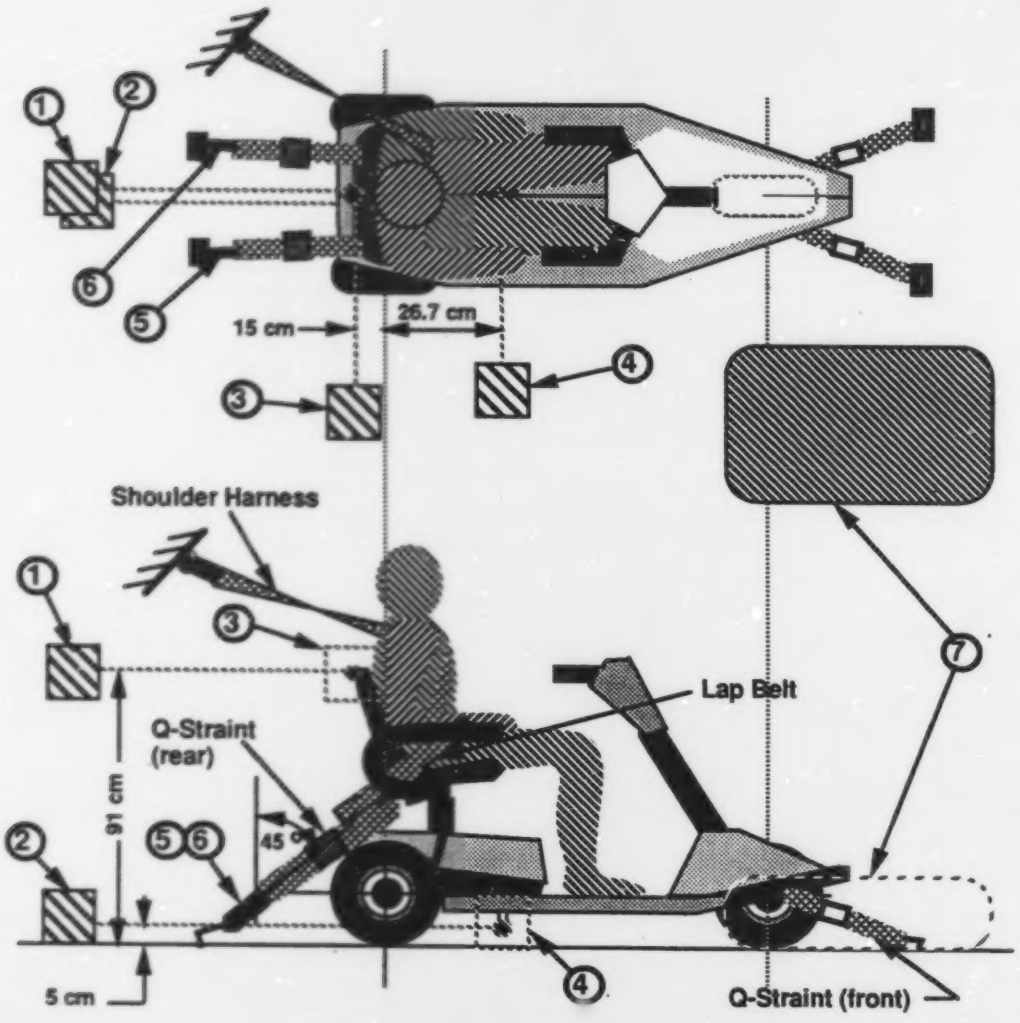
MTO provided and installed instrumentation to measure:

1/ angular displacements and velocities, and linear accelerations, of the vehicle along and about three mutually perpendicular planes at the chassis floor;
2/ longitudinal and lateral displacement at the scooter seat;
3/ longitudinal and lateral displacement at the scooter base;
4/ load in each of the two rear harness tie-down straps; and
5/ vehicle speed.

The vehicle attitudes, rates, and acceleration were measured from a gyro package that provided all required responses.

The location of the displacement transducers is shown in Figure 4. The scooter base motion was measured at a point 26.7 cm forward of the rear axle and 5 cm above floor level, a point estimated as the intersection of roll and pitch axes of the scooter. The lateral and longitudinal motion of the seat was measured near the top of the back of the seat, 15.2 cm aft of the rear axle centerline and 91.5 cm above floor level. These measurements were reduced to show left and right lateral shift, fore and aft shift, left and right roll angles, and fore and aft pitch angles, as shown in Figure 5. Figure 6 shows all this instrumentation, and parts of the data acquisition system.

The front and rear Q-Straint tie-downs are shown in Figure 7. The instrumented force links can be seen in the rear tie-down.



Transducers

1 Scooter Seat Longitudinal Displacement
2 Scooter BaseLongitudinal Displacement
3 Scooter SeatLateral Displacement
4 Scooter Base Lateral Displacement
5 Right Rear Tie-Down Force
6 Left Rear Tie-Down Force
7 Lateral, Longitudinal Accelerometers and Gyro Package

Figure 4/ Transducer Locations

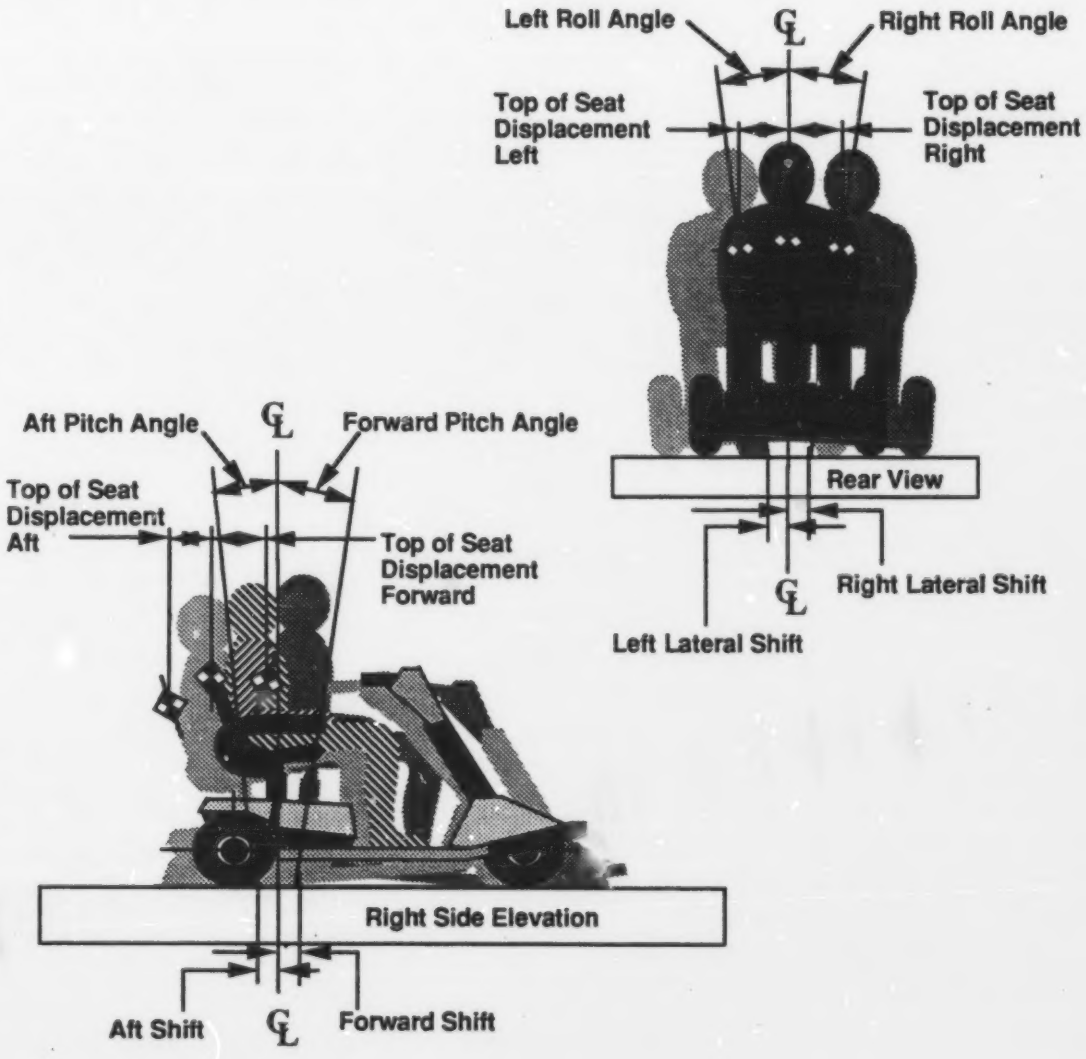
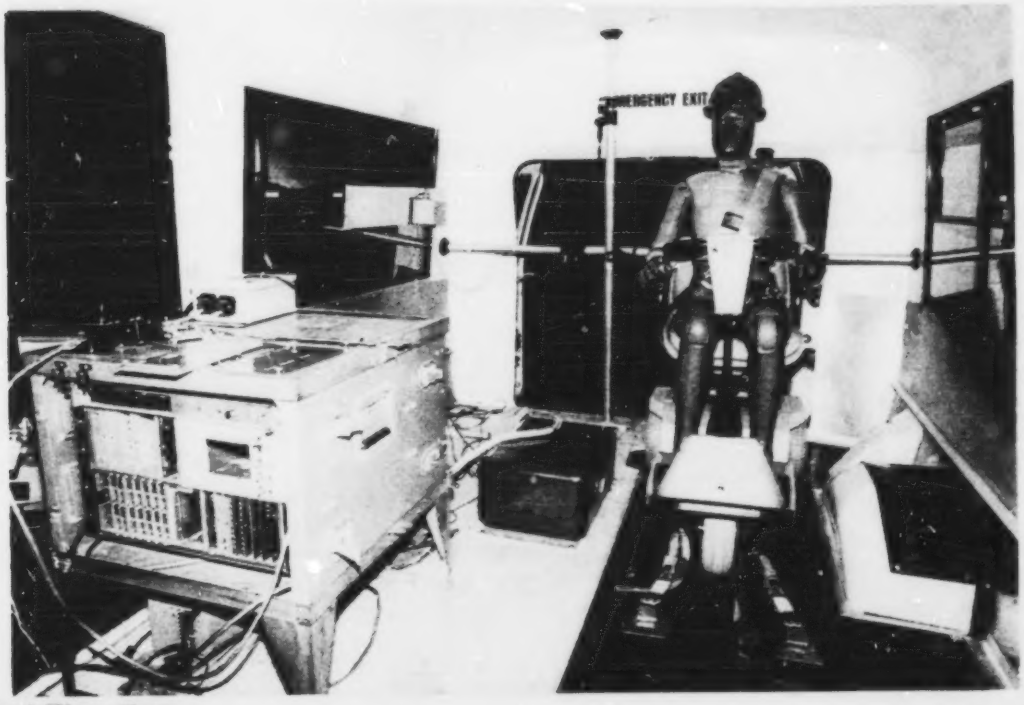
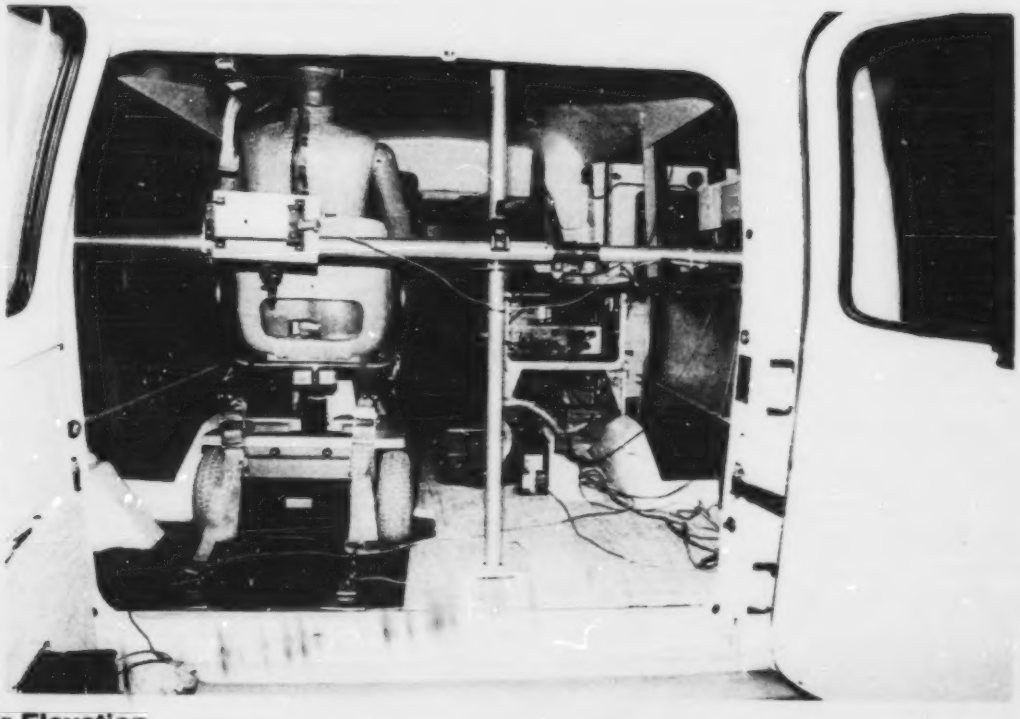


Figure 5/ Linear and Angular Displacements of Scooter

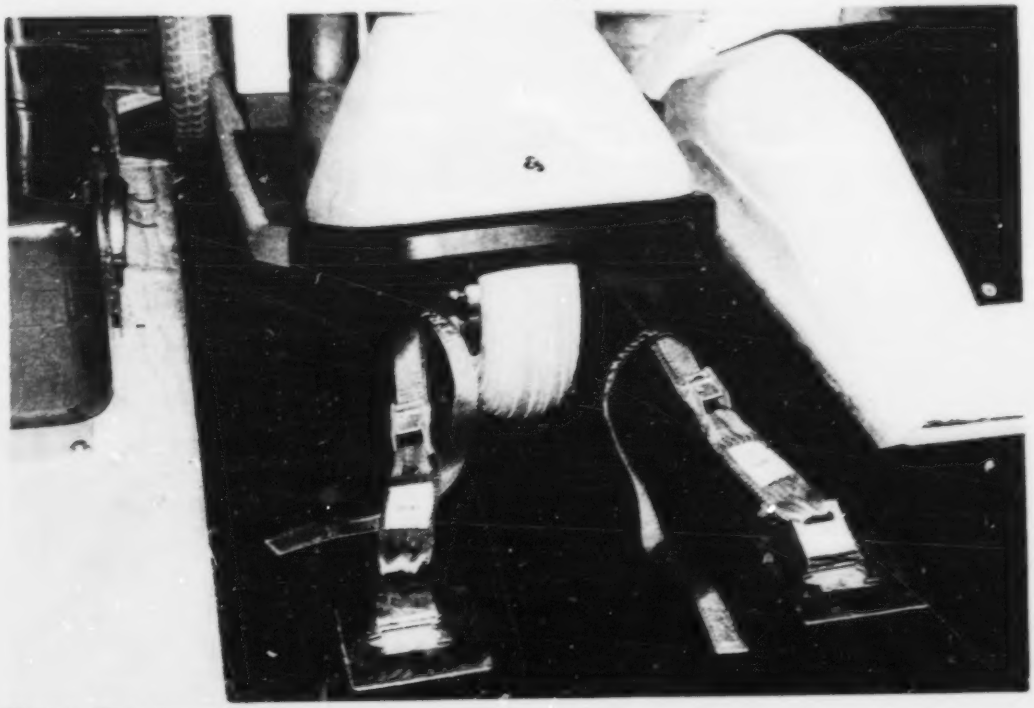


Front Elevation

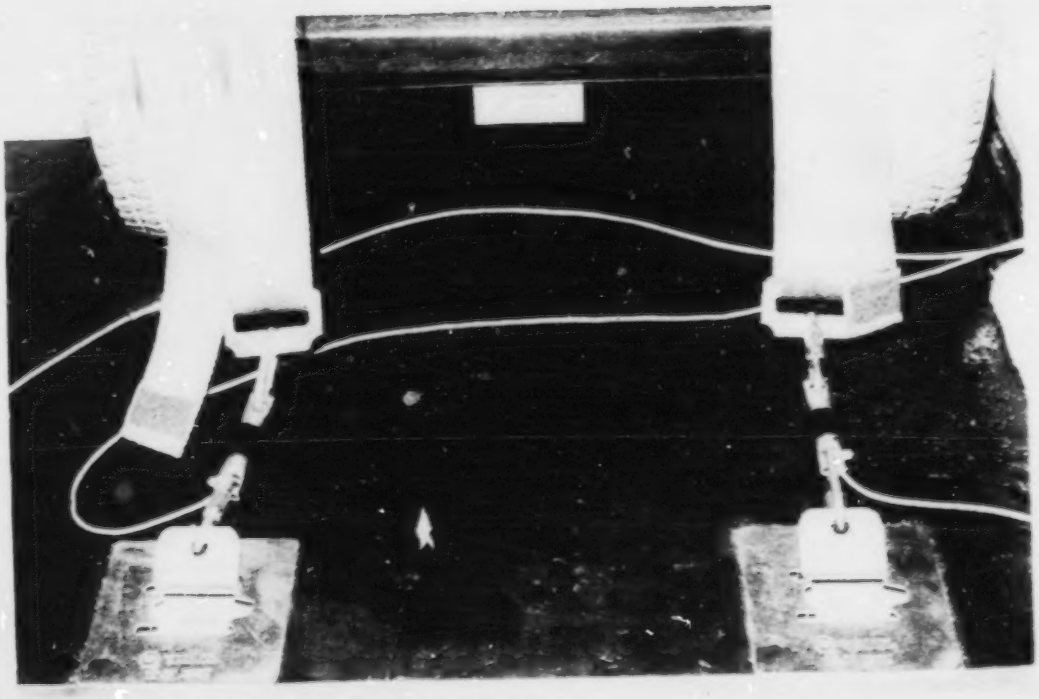


Rear Elevation

Figure 6/ Views of Scooter, Instrumentation, and Data Acquisition Systems



Front Tie-down



Rear Tie-down Straps with Force Links

Figure 7/ Q-Straint Tie-downs

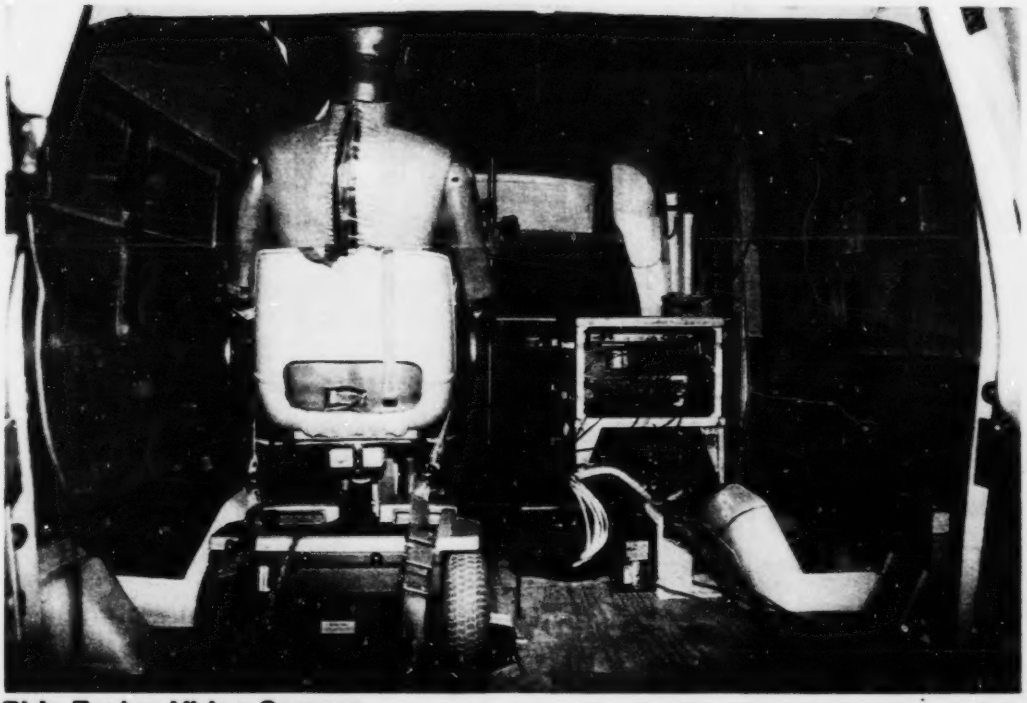
Data from the instrumentation was acquired into a 40-channel PCM telemetry system. The data captured during the tests was transformed to engineering units, and processed using a PC-based system.

Two distinct video systems were used in this test. The on-board system comprised two cameras, focussed on different areas of the scooter. A low camera was mounted with a lateral exposure, trained on the right rear tire of the scooter. The tire and ground reference were marked such that relative motion could be detected by the camera. The second camera was trained on the scooter from close to the centreline of the vehicle, just behind the driver and passenger seats, to record any lateral sway and pitch motion. These cameras are shown in Figure 8. The second system was a hand-held camera used to record external views of the various test runs, and other aspects of interest.

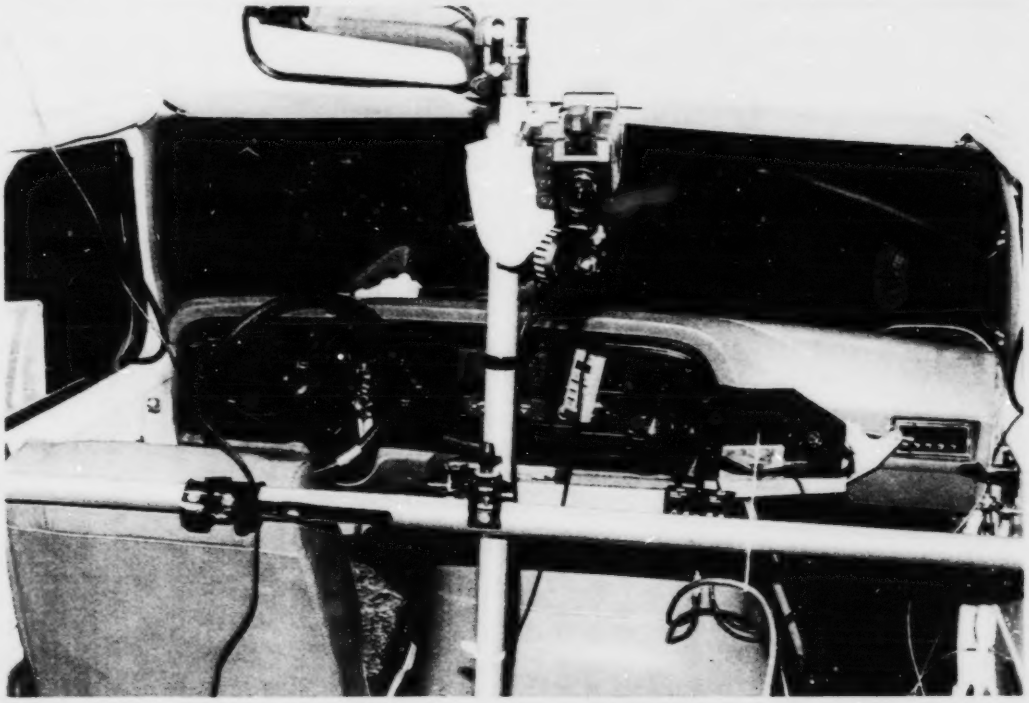
MTO conducted a balance analysis on the scooter and dummy. The results are as follows:

Location	**Scooter Empty**	**Scooter with Dummy**
Left Rear Wheel	229 N	438 N
Right Rear Wheel	253.4 N	507 N
Front Wheel	215.7 N	364.7 N
Total	**698.1 N (157 lb)**	**1309.7 N (294.5 lb.)**

The location of the center of gravity for the scooter, dummy, and combination are shown in Figure 9.



Side Facing Video Camera



Facing Video Camera

Figure 8/ Locations of Video Cameras

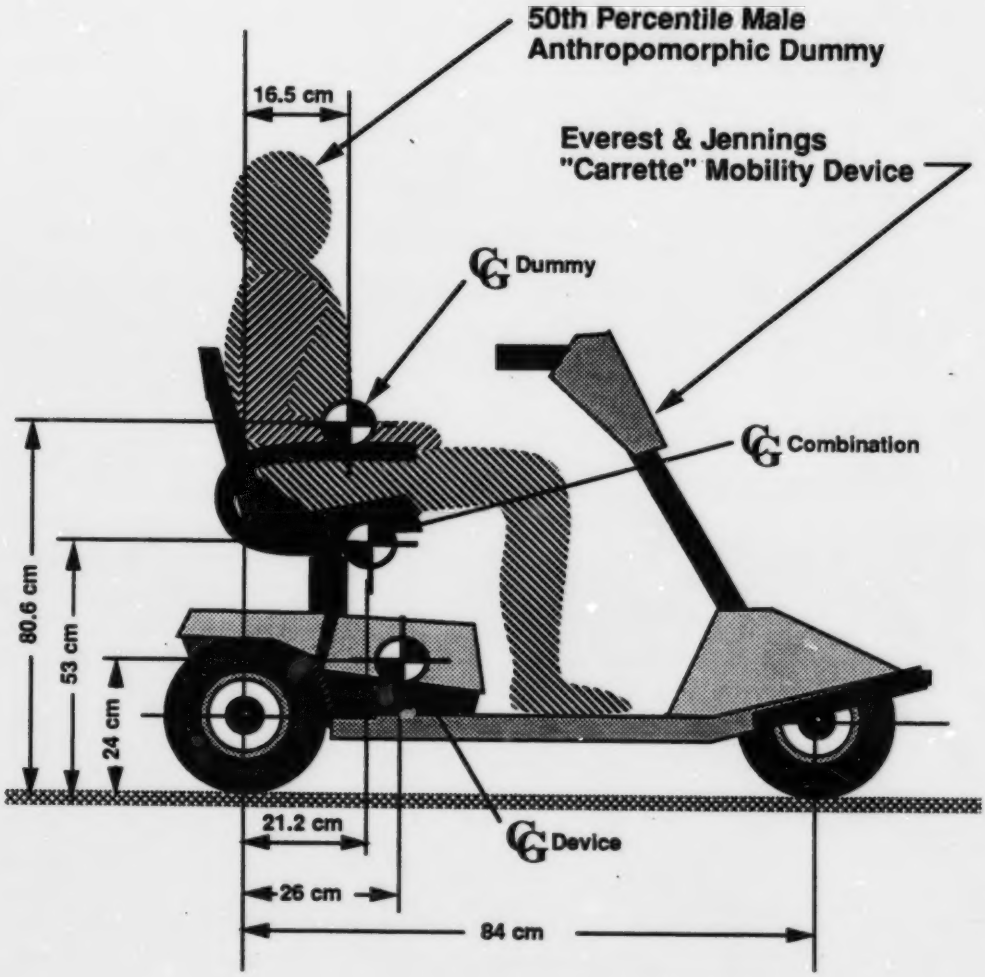


Figure 9/ General Arrangement and Center of Gravity of Scooter and Dummy

5/ TEST PROGRAM

5.1/ Acceleration, per D409

Accelerate at full throttle from a standstill to 40 km/h (25 mph) on dry pavement.

5.2/ Braking, per D409

Apply maximum braking from 35 km/h (22 mph) to a standstill on dry pavement.

5.3/ Constant Radius Turn, per D409

Drive with the outer front wheel on a circle of 30 m (100 ft) diameter at a steady speed of 26 km/h (16 mph). This was done in both directions, with and without the dummy. The course is shown in Figure 10.

5.4/ Double Lane Change

This test represents the kind of emergency manoeuvre a driver would make to avoid an obstacle in its traffic lane. The driver approaches a lane marker at a steady speed and steers to enter an adjacent lane. After a short distance in this lane, the driver returns to the original lane. The track layout for this test employs a 3.05 m (10 ft) wide approach lane, an opening gate of 19.29 m (60 ft) to enter the adjacent lane, a distance of 9.14 m (30 ft) in this lane, and an opening of 19.29 m (60 ft) to return to the original lane. The course is shown in Figure 11. The test is executed in both left and right directions, at speeds of 50, 55, 60, 65, 70, and 75 km/h. The test is limited by the lateral acceleration capability of the vehicle.

5.5/ Spiral 90° Right Turn

This test represents driving through a 90° channelized turn, ramp, or right-hand turn at high speed. The spiral turn produces a progressive increase in lateral acceleration on the vehicle. The vehicle is driven in a straight line at constant speed into a marked transition spiral and curve that exits 90° from the approach direction. The spiral causes the vehicle to turn from an infinite radius to a 36.6 m (120 ft) centerline radius while rotating through a 60° turn. The remaining 30° portion of the turn to egress is at a constant 36.6 m (120 ft) radius. The length of the spiral trajectory is 76.69 m (251.6 ft) and the constant radius trajectory is 19.14 m (62.8 ft) long. The test is conducted using a spiral to right only, at speeds of 45, 50, 55, and 60 km/h. This course is shown in Figure 12.

5.6/ Constant Radius Turn

This test represents driving at high speed on a 270° circular freeway ramp. The test requires that the vehicle be driven in a circle on a flat surface at constant speed. The

Figure 10/ Constant Radius Turn

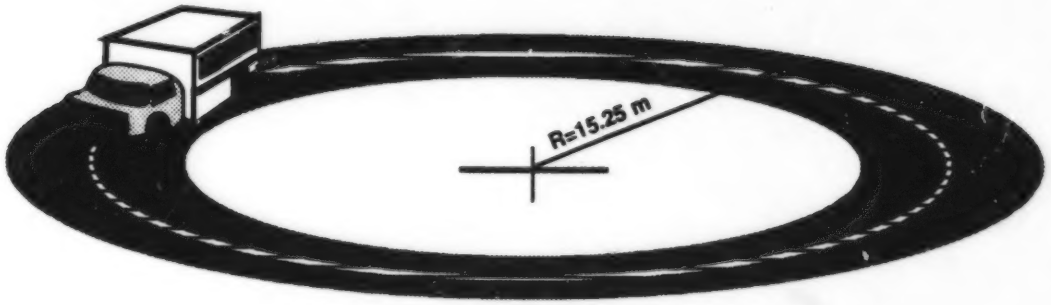
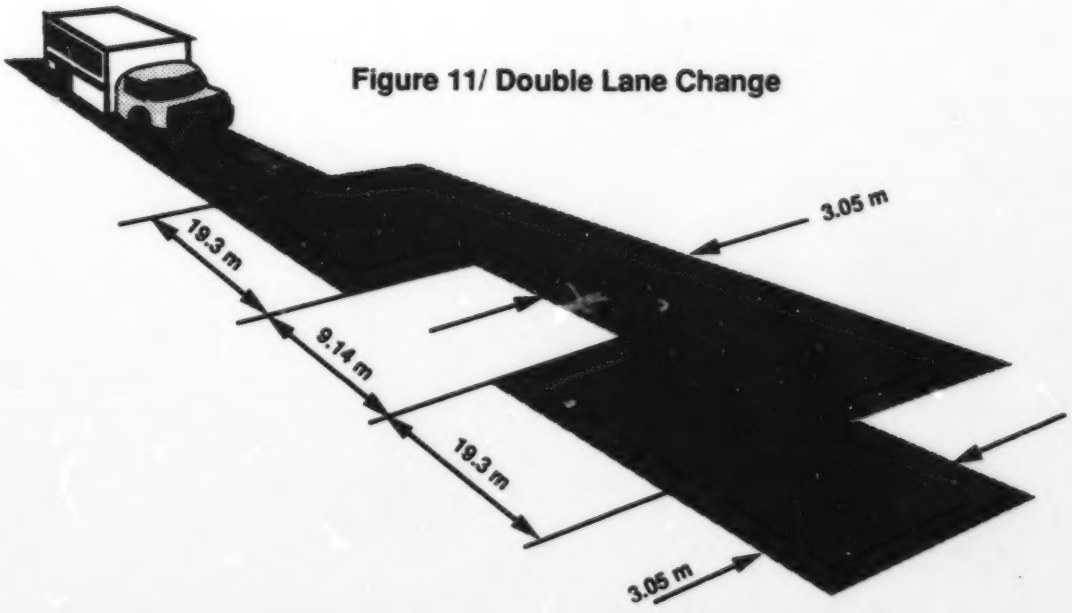


Figure 11/ Double Lane Change



vehicle is accelerated up to test speed on a constant radius circle of 15.25 m (50 ft), Figure 10. After several laps the speed is increased and this process continues until the limit of control for the vehicle is reached. This test is done in both left and right turn directions, commencing at 20 km/h, and increasing in increments of 5 km/h up to the speed at which the driver can no longer safely hold the vehicle on the course. This is similar to the D409 constant radius turn, but provides higher lateral accelerations.

5.7/ J-turn

This test provides an abrupt input to the vehicle. The driver approaches the test area in a straight line at a constant speed of 50 km/h and then executes a ramp steer input of one complete steering wheel revolution at the highest possible steer rate, and holds the steer angle until the vehicle achieves steady state. The test is done in both left and right directions. This is shown in Figure 13. Unlike the spiral and constant radius turns, where the driver steers to follow a prescribed path, in this test the steer is prescribed and the vehicle goes where that takes it. It is an abbreviated version of a standard test used to evaluate transient dynamics of vehicles.

5.8/ Abrupt Braking

This braking test represents a wheels-locked emergency stop. It is not, nor is it intended to be, a maximum performance brake application. The vehicle is driven at constant speed and then braked aggressively using full pedal travel and the brakes are held on for the duration of the slide. This is done from an initial speed of 80 km/h on a high-friction surface. The driver does not attempt to correct any direction change during the slide. It provides deceleration similar to that experienced in the D409 brake test, but of longer duration.

5.9/ Snub Braking

This braking test is designed to create a longitudinal pitch frequency in the vehicle close to the system natural frequency and hence produce a pulsating inertial loading. The vehicle approaches the test area at a constant speed of 50 km/h. The driver then applies and releases the brakes rapidly in a pulsating manner. The scooter response was monitored and compared to the input deceleration and frequency to determine if any abnormal loading or motion was present.

5.10/ Back-up Braking

This test is designed to produce a rearward acceleration somewhat higher than that provided by the D409 acceleration test. It is important from the standpoint that the dummy is only restrained by the seatback in this test and not the shoulder harness as in the forward deceleration mode. The vehicle was driven in reverse, at fast idle speed, and the driver braked aggressively using full pedal travel to bring the vehicle to a stop.

Figure 12/ Spiral 90° Turn to Right

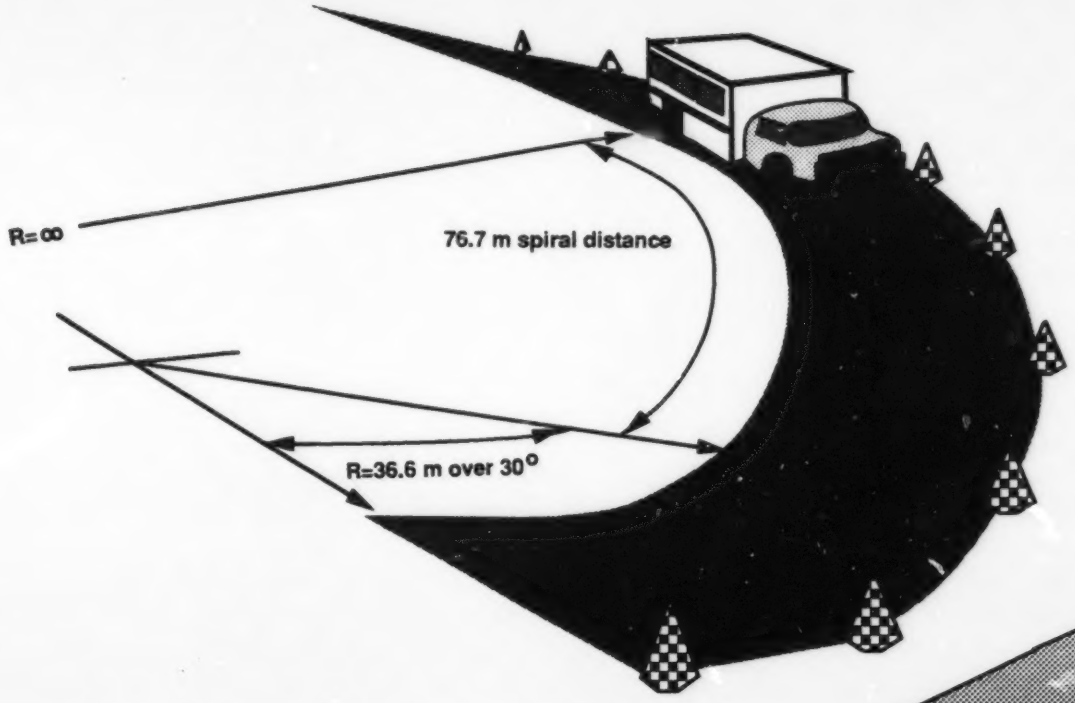
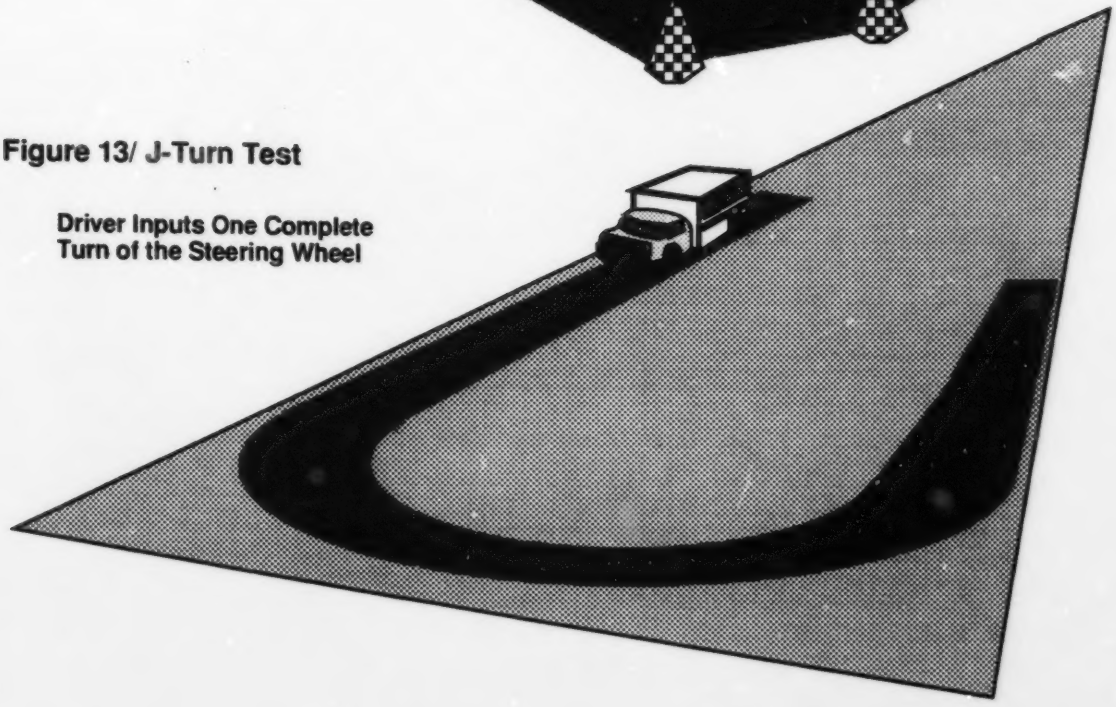


Figure 13/ J-Turn Test



5.11/ Test Matrix

D409 Tests

Test	Runs	Speed
1/ Acceleration	2	0 to 40 km/h
(Wide open throttle, low range transmission setting)		
2/ Deceleration	2	35 to 0 km/h
(2.1) With dummy		
(2.2) Without dummy		
3/ Steady turn(30 m D)	2L and 2R	26 km/h
(3.1) With dummy		
(3.2) Without dummy		

Severe Driving Tests (Lateral)

Test	Runs	Speed
4/ Double lane change	2L	50, 55, 60, 65, 70, 75 km/h
5/ Spiral turn	2R	45, 50, 55, 60 km/h
6 Constant radius (15.25 m R)	2R	20 + in steps of 5 km/h
(6.1) scooter tires at 245 kPa (35 psi), tie-down at Max load		
(6.2)scooter tires at 105 kPa (15 psi), tie-down at Max load		
(6.3) scooter tires at 105 kPa (15 psi), tie-down at Min load		
7/ J-turn	2L and 2R	50 km/h

Severe Driving Tests (Longitudinal)

Test	Runs	Speed
8/ Abrupt braking	2	80 to 0 km/h
9/ Snub braking	2	From 50 km/h
10/ Back-up braking	2	From high idle speed to 0

6/ OBSERVATIONS AND RESULTS

6.1/ Acceleration, per D409

This test subjected the vehicle to a peak initial longitudinal acceleration of 0.33 g. This subsided to an average of 0.17 g once the vehicle was in motion. During this test, the base of the scooter displaced 0.16 cm rearward, the seat displaced 0.75 cm rearward and the maximum pitch angle was 0.4° rearward. Summary curves of acceleration, displacement, and tie-down forces are shown in Figure 14. Data from a run are are shown in Figure 15, where responses are plotted against longitudinal acceleration. It can be seen that the scooter displacement was related to longitudinal acceleration in a linear manner up to 0.33 g. It can also be seen from this test that the scooter base excursion was minimal, and would meet the requirements of D409. The scooter promptly returned to its initial position when the acceleration ceased. The only restraint rearward on the dummy was the seatback, and flexing of this member and its support account for the physical displacement of the seat.

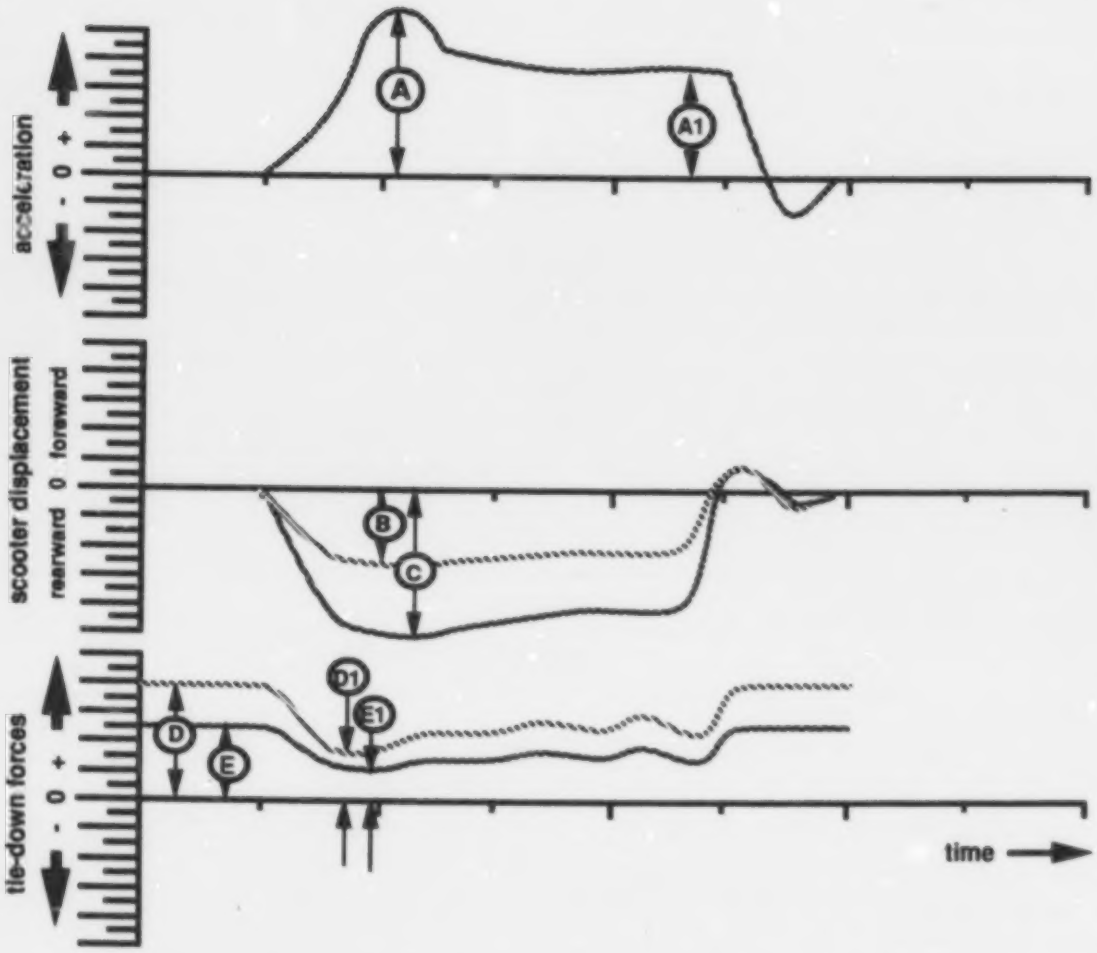
6.2/ Braking, per D409

This test subjected the vehicle to an average maximum sustained longitudinal deceleration of 0.77 g, which was the maximum that could be achieved given the specific vehicle suspension/tire/surface conditions. The deceleration stayed relatively uniform throughout the manoeuvre. The base of the scooter moved 0.55 cm forward and the seat moved 1.07 cm forward during this test. The maximum pitch angle was 0.4° forward. Summary curves of deceleration, displacement,and tie-down forces are shown in Figure 16. Data from a run are shown in Figure 17, with responses plotted against longitudinal acceleration. The fore and aft displacements in Figure 17 are a result of pitching of both scooter and vehicle after the vehicle had stopped, as a result of their respective suspensions and tires. This provided displacements almost as large as the initial results.

It can be seen from this test that the scooter excursion was larger than the previous test, but so was the disturbing force. It still met the requirements of D409. The scooter promptly returned to its initial position when the deceleration ceased. The dummy was restrained from forward motion directly by the restraint system of shoulder strap, lap belt, and rear tie-downs. From Figure 17 it can be seen that scooter displacement and rear tie-down strap forces were related to longitudinal acceleration in a linear manner up to 0.77 g.

6.3/ Constant Radius Turn, per D409

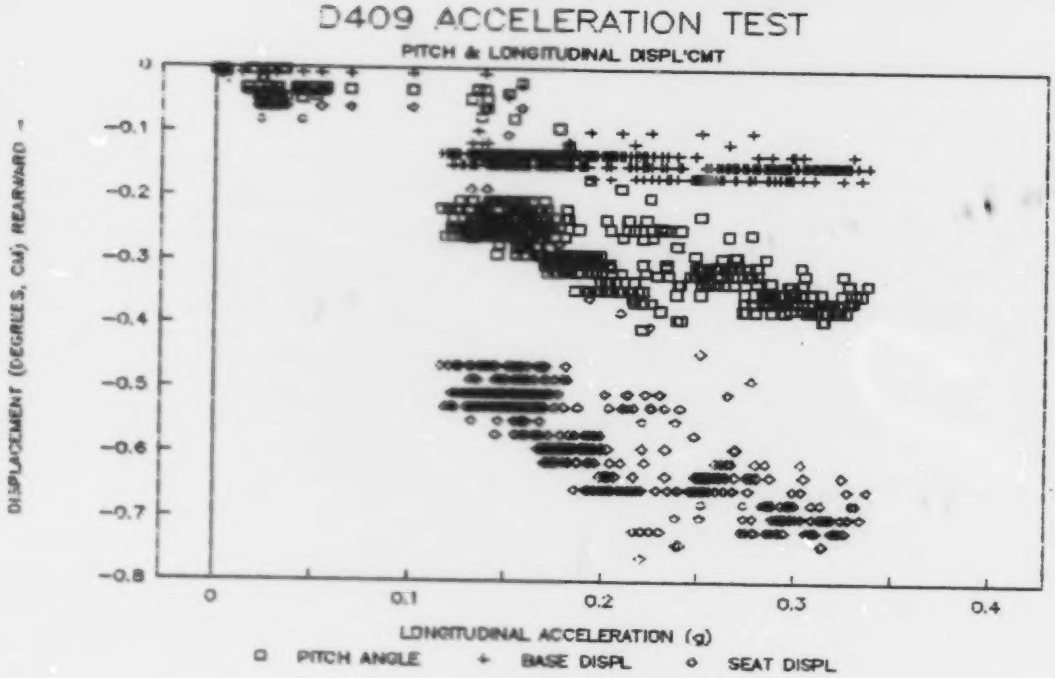
This test subjected the vehicle to an average maximum sustained lateral acceleration of 0.38 g, which is slightly above the maximum derived from the specific test criteria. The acceleration stayed relatively uniform throughout the manoeuvre. During the clockwise, or right-turn test, the base of the scooter displaced 0.55 cm to the left, the



Average results from maximum performance acceleration in lowest range transmission setting, to 40 km/h, two runs.

A - Maximum Longitudinal Acceleration	**0.33 g**
A1- Stabilized Longitudinal Acceleration	**0.17 g**
B - Scooter base maximum displacement	**0.16 cm**
C - Scooter seat maximum displacement	**0.75 cm**
D - Initial Left Tie-down Load	**0.22 kN**
D1- Minimum Left Tie-down Load	**0.12 kN**
E - Initial Right Tie-down Load	**0.59 kN**
E1- Minimum Right Tie-down Load	**0.38 kN**
Maximum Scooter Pitch Angle	**0.4°**

Figure 14/ D409 Acceleration



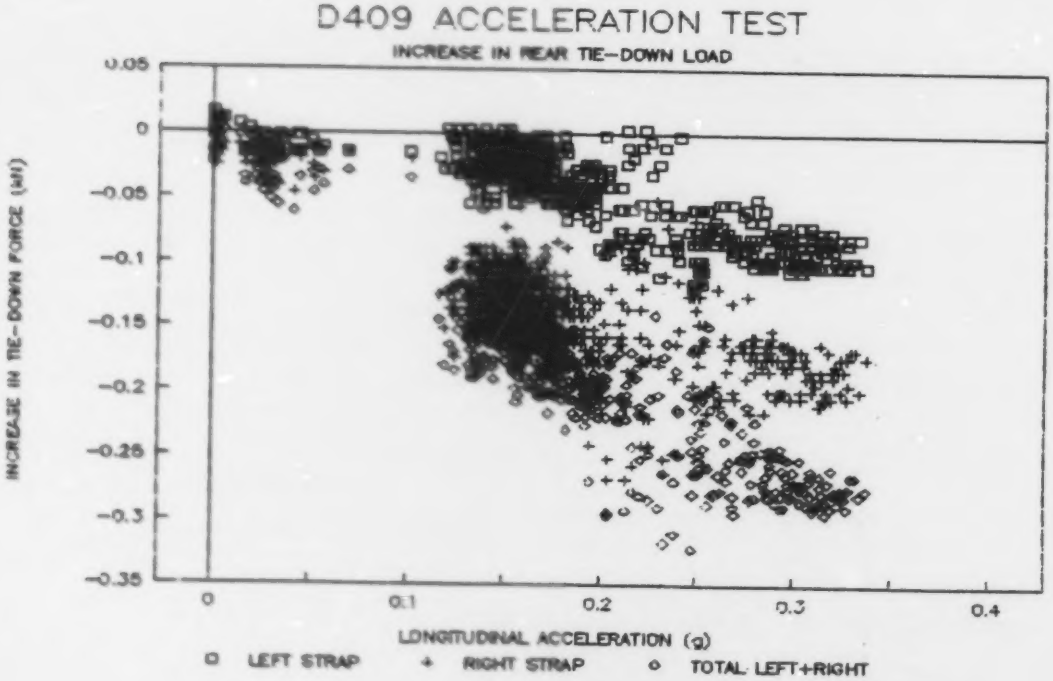
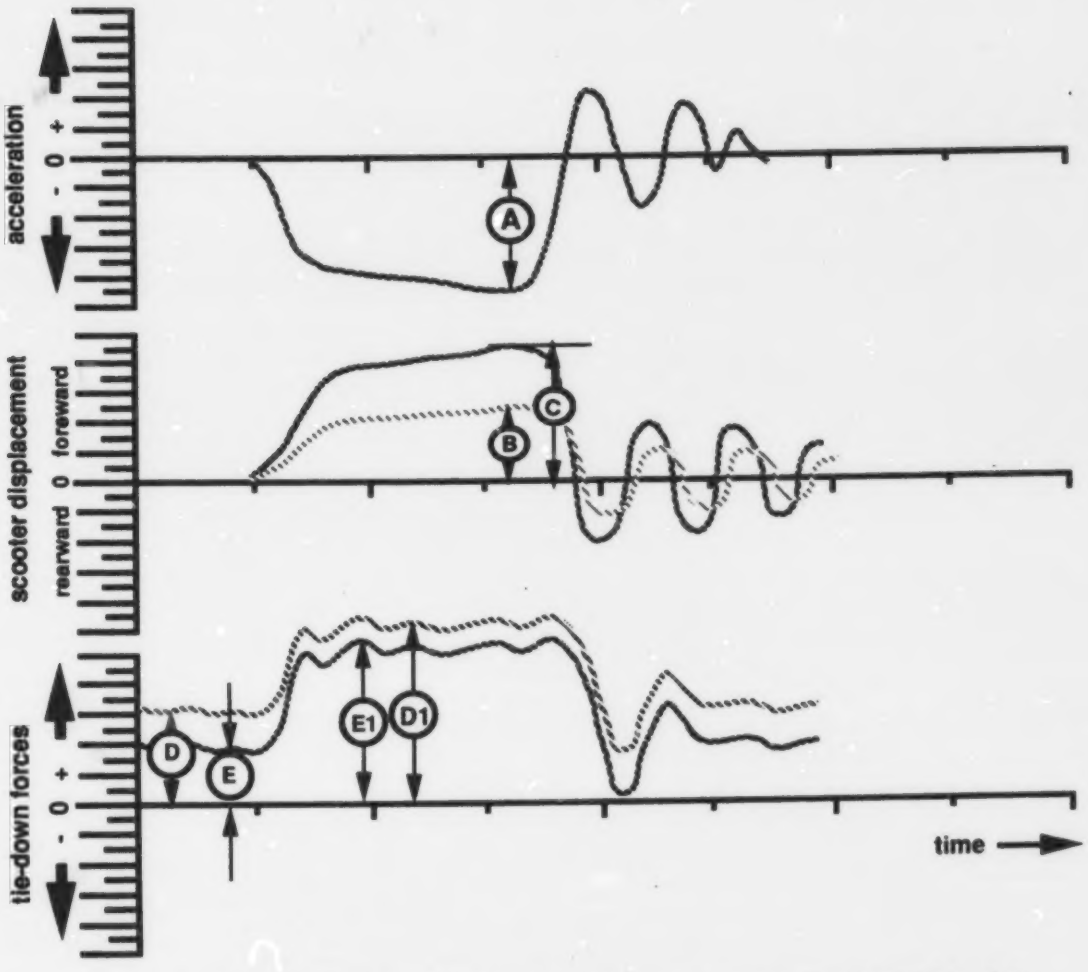


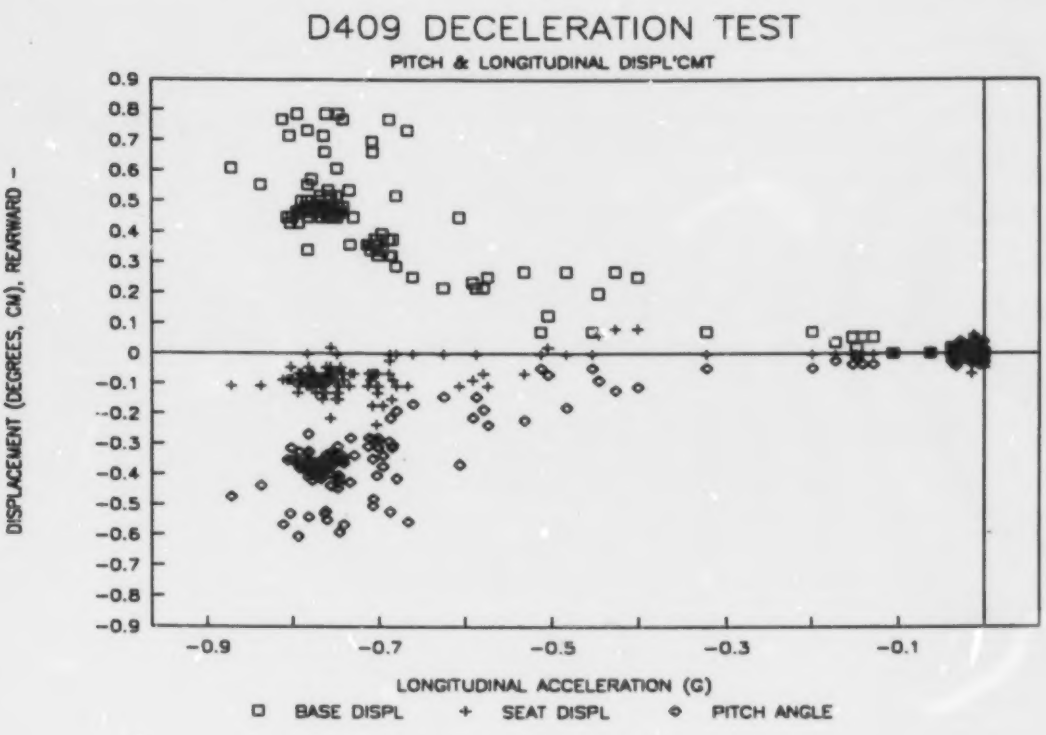
Figure 15/ D409 Acceleration Test



Average results from maximum performance deceleration from 35 km/h to full stop, two runs.

A - Maximum Longitudinal Deceleration	0.77 g
B - Scooter base maximum displacement	0.55 cm
C - Scooter seat maximum displacement	1.07 cm
D - Initial Left Tie-down Load	0.90 kN
D1- Maximum Left Tie-down Load	1.32 kN
E - Initial Right Tie-down Load	0.77 kN
E1- Maximum Right Tie-down Load	1.28 kN
Maximum Scooter Pitch Angle	0.4 °

Figure 16/ D409 Deceleration



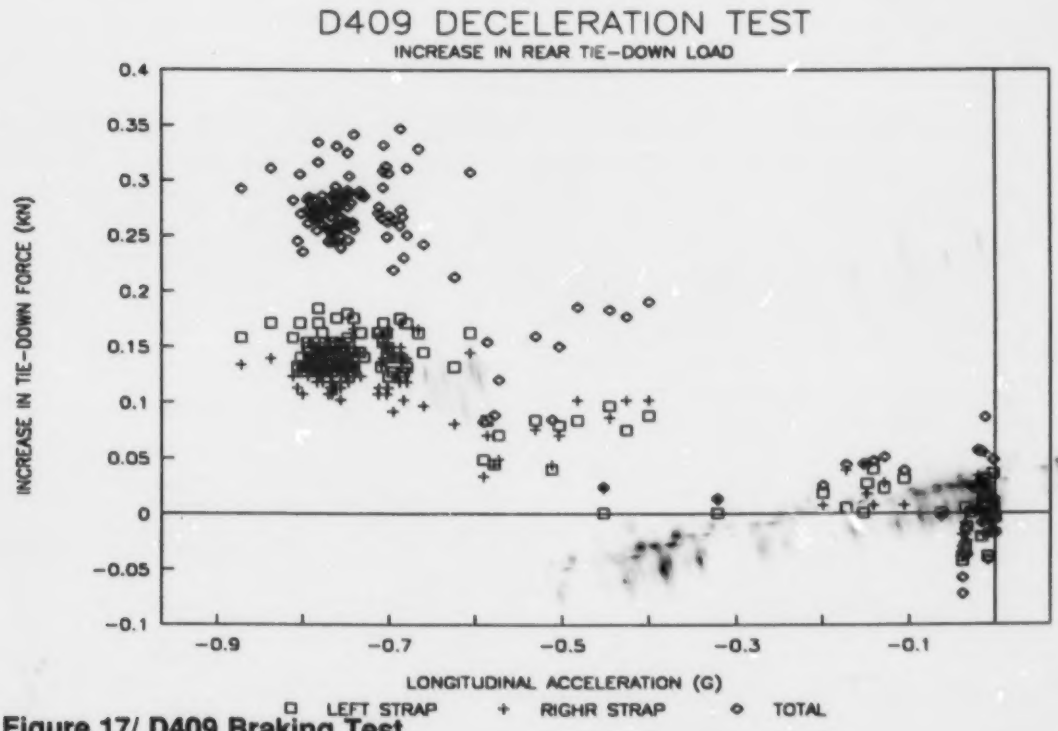


Figure 17/ D409 Braking Test

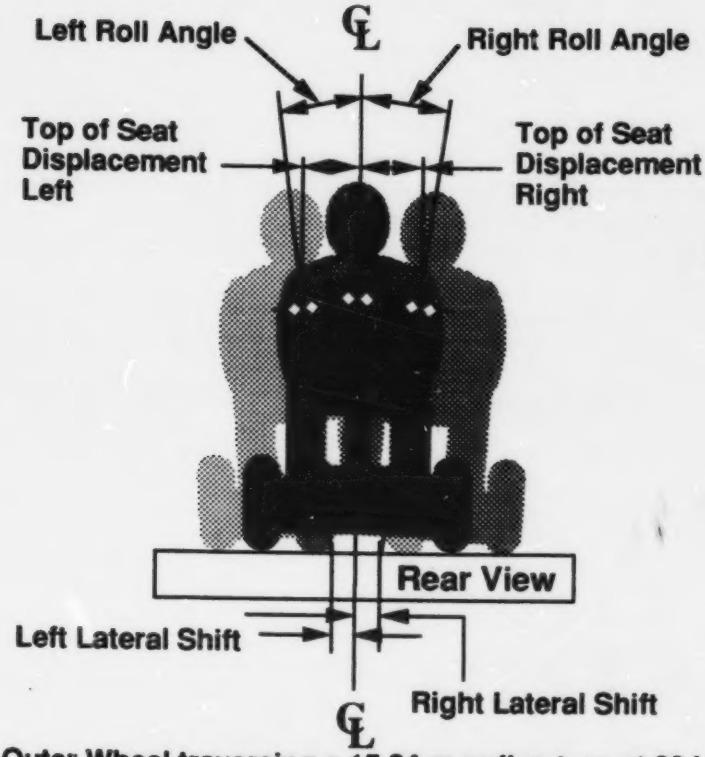
seat displaced 6 cm left, and the maximum sustained scooter relative roll angle was 3.61° left. During counterclockwise, or left-turn test, the base of the scooter displaced 0.37 cm to the right, the seat displaced 3.76 cm right, and the maximum sustained scooter relative roll angle was 2.25° right. In both directions, the scooter base motion met the strict terms of D409. However, the roll angle of the scooter resulted in what might best be described as excessive sway of the seat and dummy. The average responses from this test are shown in Figure 18. The difference in scooter seat responses between left and right turns appear to be a result of the lateral restraint of the shoulder strap, which tends to curtail lateral torso translation, and hence scooter roll, to the right. The restraining ability of the shoulder harness toward the left is less, because the strap on the dummy's left shoulder allows for lateral motion to the left. The shoulder harness could have been made tighter, but not without likely discomfort to an actual rider. This test was also performed without the dummy and the resulting scooter seat motions were approximately 10% of those measured during the tests with the dummy, as also shown in Figure 18.

Data from the runs are shown in Figure 19. The oscillations seen in Figure 19 are as a result of minor track-induced disturbances, and driver course corrections, that manifest themselves in slight chassis sway. The amplitude is about 0.5 cm of displacement or 0.5° of roll. In this test the scooter base remained relatively stationary while the seat moved. The scooter seat promptly returned to its initial position when the lateral acceleration ceased.

6.4/ Double Lane Change

In this test the vehicle was subjected to an abrupt change in lateral acceleration, first to the left, then the right, then left again. The general traces of the input are shown in Figure 20 with a corresponding drawing showing the vehicle's relative position on the course. The summary curves of maximum scooter roll angle, shown in Figure 20, show a relatively linear relationship between the vehicle speed in the manoeuvre and the scooter roll angle. A similar relationship can also be seen for increase in tie-down tension. The lateral shift of the scooter base is shown in Figure 21. It shows peak excursions of up to 2.25 cm on the faster runs, where the lateral acceleration reached about 0.8 g. The top of seat displacements, also shown in Figure 21, show one to three cm upon completion of the run. The excursions of the scooter appeared to be somewhat linear with the lateral acceleration input ramp. The oscillation at the peaks of the faster runs were as a result of the vehicle sliding, causing a tire/suspension vibration that reflected in the lateral motion of the scooter, that is not shown in the schematic lateral accelerations in Figure 20. Although the vehicle was sliding fairly violently at the highest speeds, it was deemed under control by the test staff and therefore data was treated as realistic for a recovery-type manoeuvre.

The data presented in Figures 22 and 23 are taken from a test run at 75 km/h and are presented here for illustration purposes only. The reduced average data is shown in



Outer Wheel traversing a 15.24 m radius turn at 26 km/h, clockwise and counterclockwise directions

		Left Turn	Right Turn
With Dummy Seated in Scooter	Left Lateral Shift		0.55 cm
	Right Lateral Shift	0.37 cm	
	Top of Seat Displ. left		6.00 cm
	Top of Seat Displ. right	3.76 cm	
	Left Roll Angle		3.61°
	Right Roll Angle	2.25°	
		Left Turn	Right Turn
Without Dummy	Left Lateral Shift		0.22 cm
	Right Lateral Shift	0.16 cm	
	Top of Seat Displ. left		0.54 cm
	Top of Seat Displ. right	0.40 cm	
	Left Roll Angle		0.21°
	Right Roll Angle	0.16°	

Figure 18/ D409 Constant Radius Turn-Shift and Roll Displacements

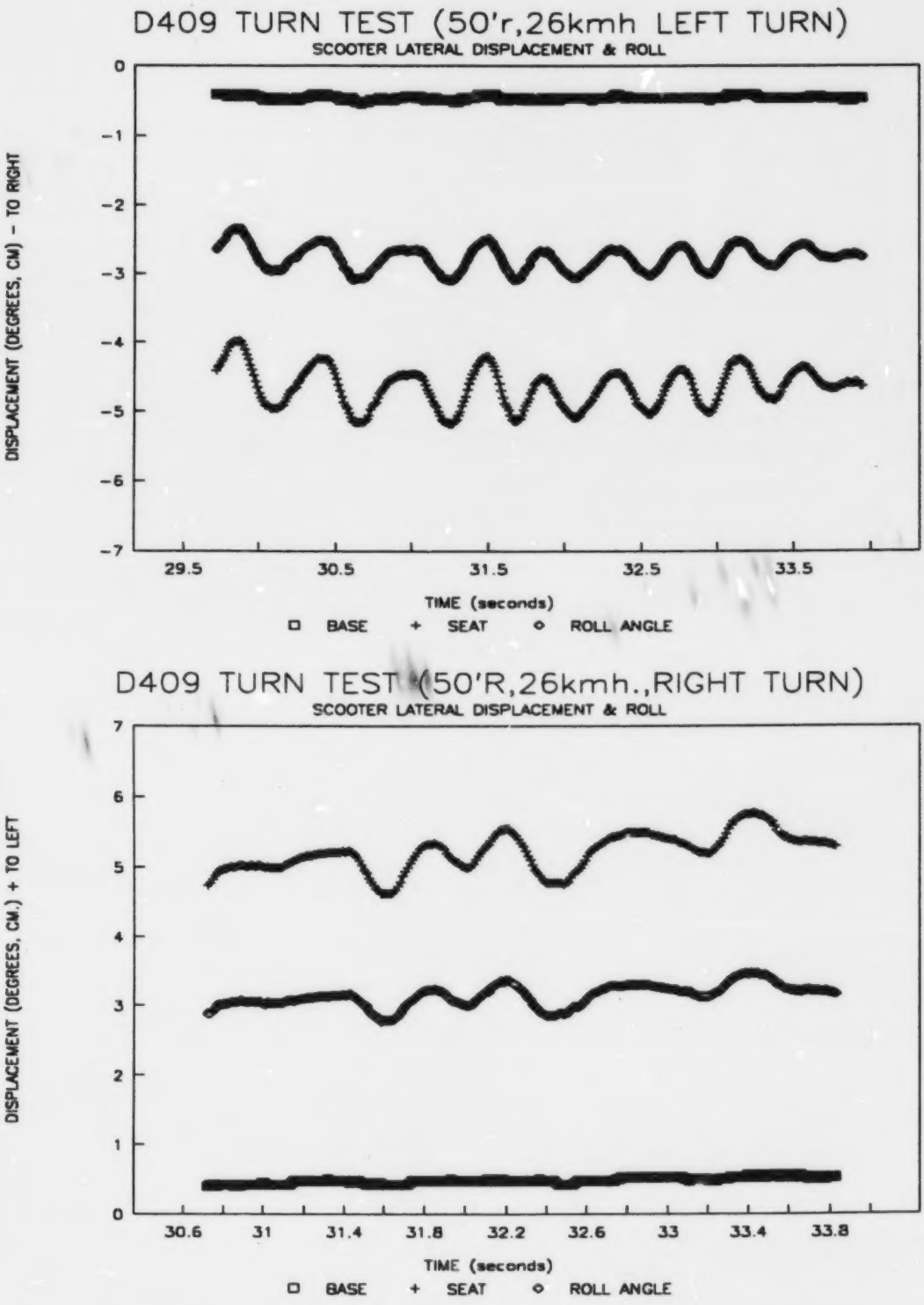
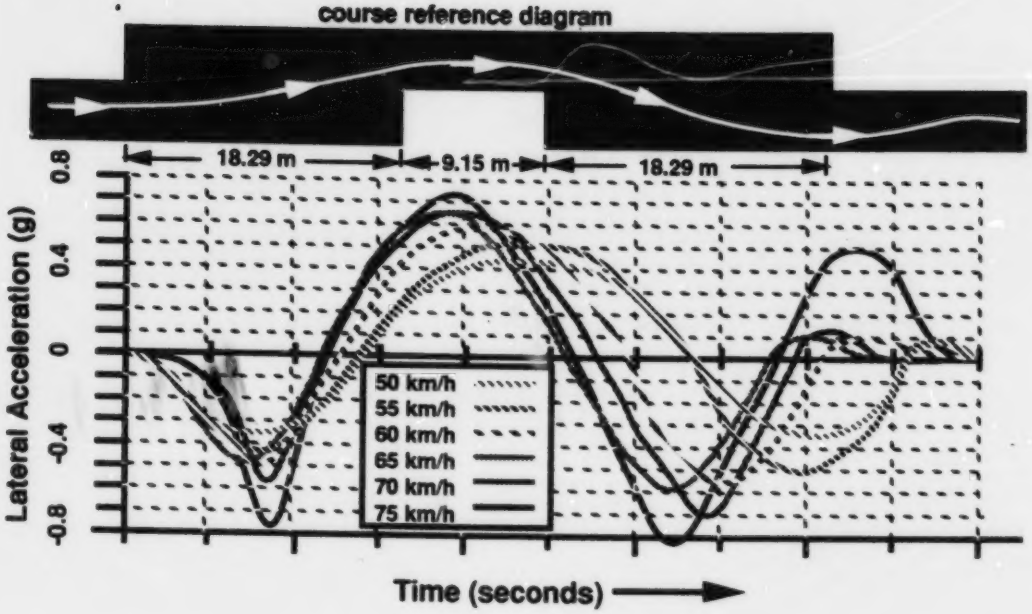


Figure 19/ D409 Constant Radius Turn



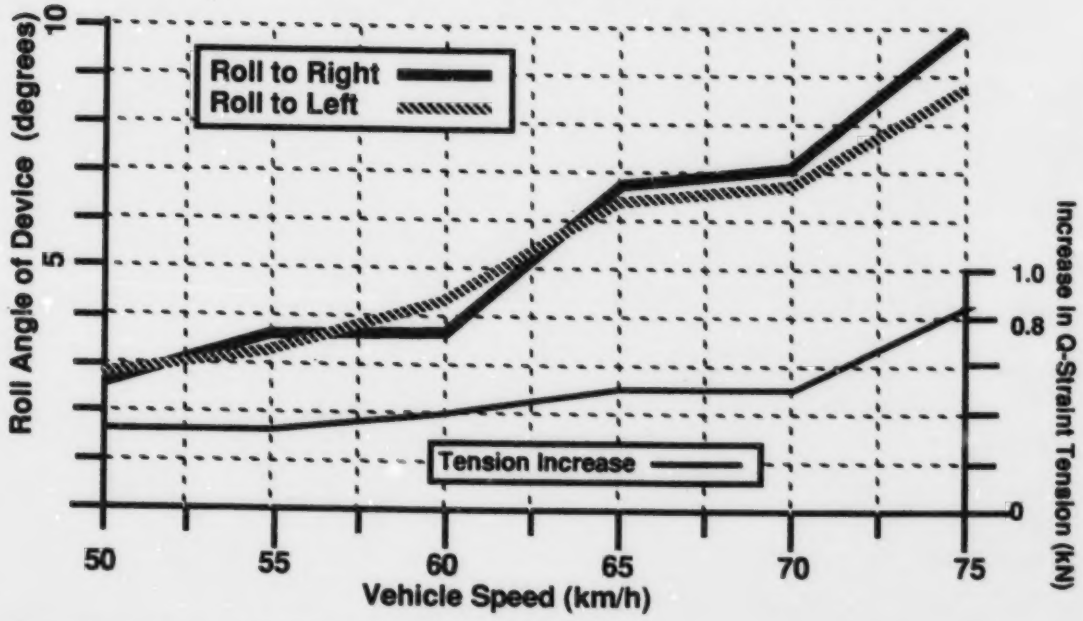


Figure 20/ Double Lane Change-
Lateral Acceleration and Roll Angle Plots

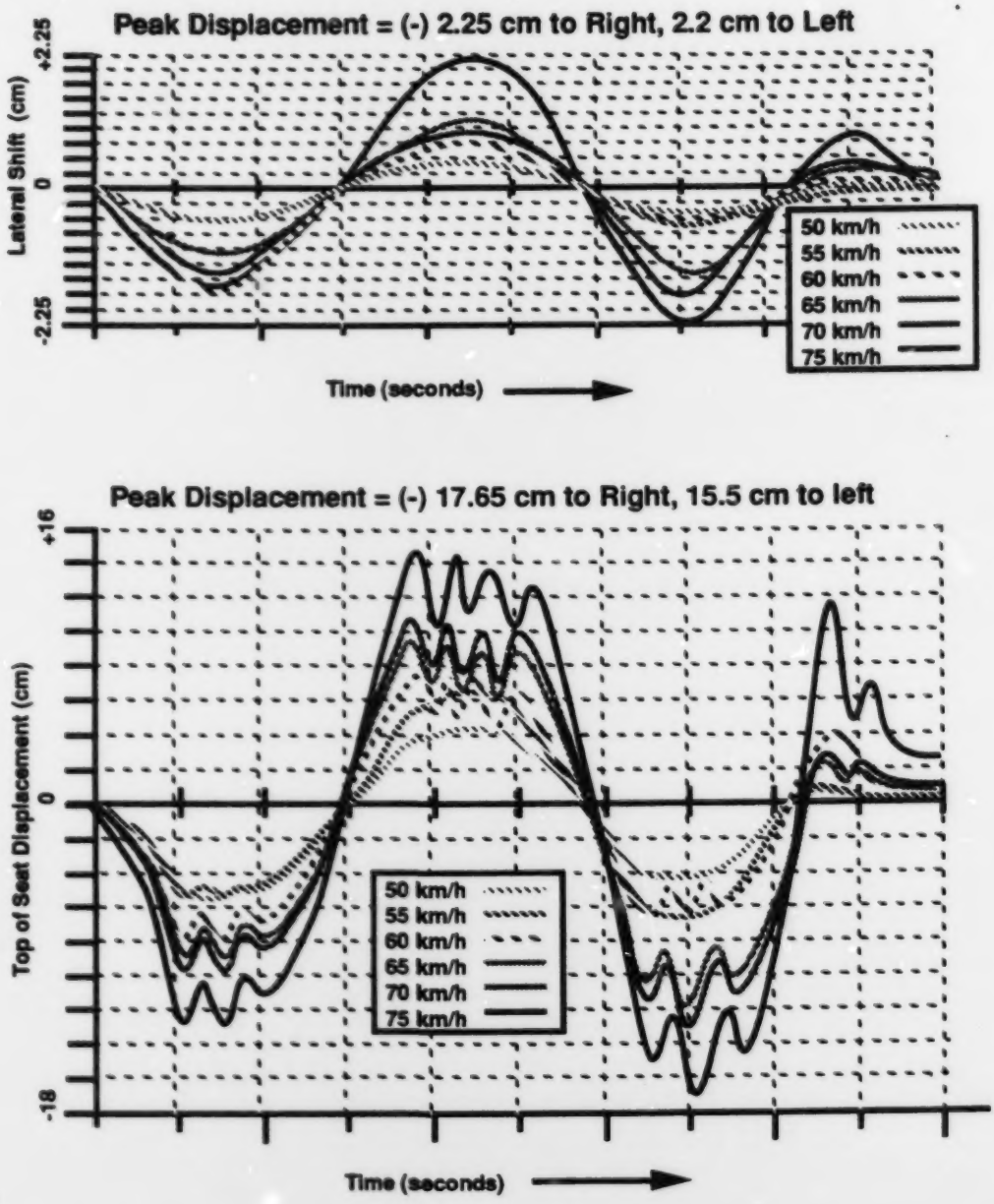


Figure 21/ Double Lane Change-
Lateral Shift and Top of Seat Displacements for Speeds 50 to 75 km/h

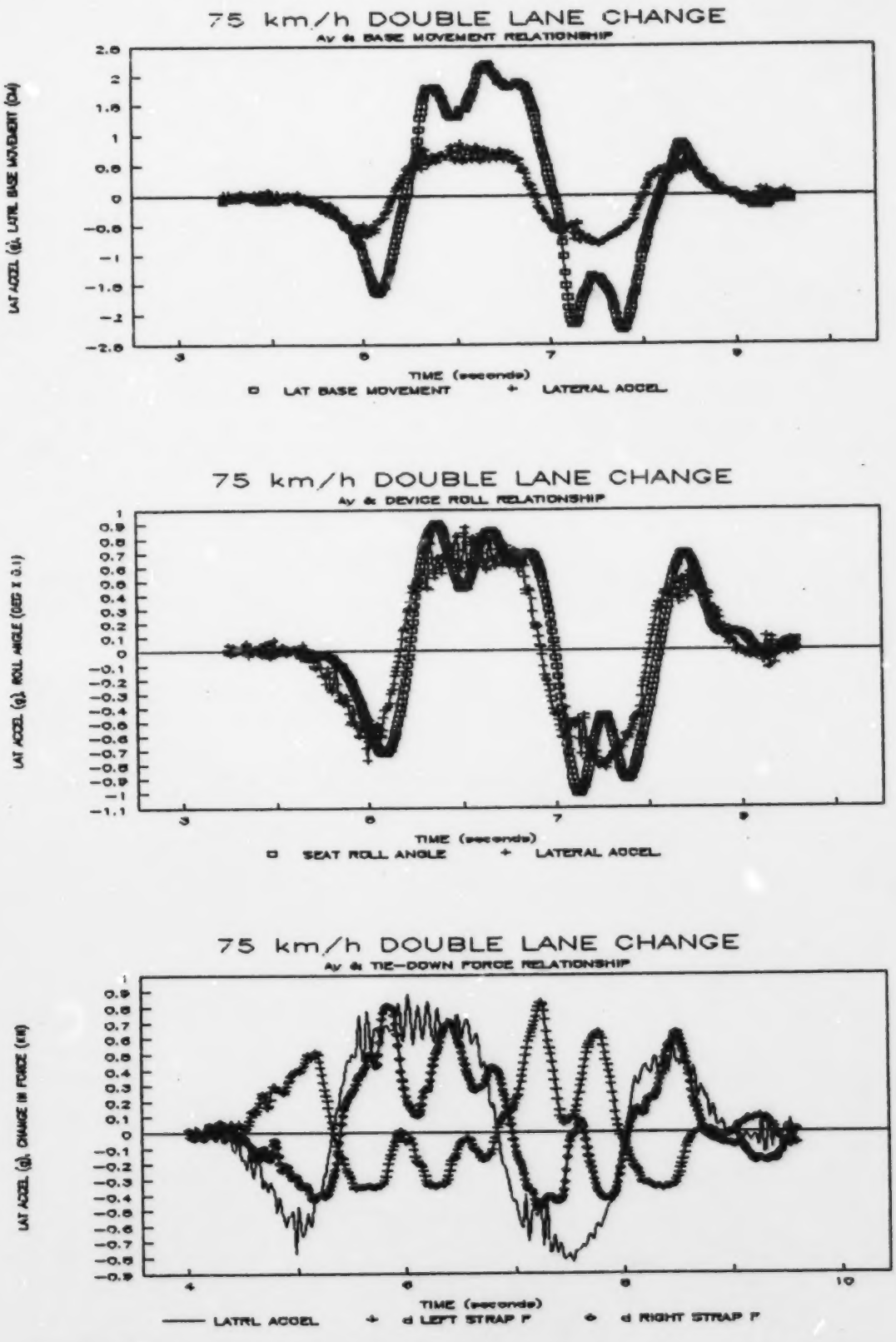

75 km/h DOUBLE LANE CHANGE
Ay & BASE MOVEMENT RELATIONSHIP
LAT ACCEL (g), LATRL BASE MOVEMENT (CM)
TIME (seconds)
LAT BASE MOVEMENT
LATERAL ACCEL
75 km/h DOUBLE LANE CHANGE
Ay & DEVICE ROLL RELATIONSHIP
LAT ACCEL (g), ROLL ANGLE (DEG X 0.1)
TIME (seconds)
SEAT ROLL ANGLE
LATERAL ACCEL
75 km/h DOUBLE LANE CHANGE
Ay & TIE-DOWN FORCE RELATIONSHIP
LAT ACCEL (g), CHANGE IN FORCE (KN)
TIME (seconds)
LATRL ACCEL
d LEFT STRAP F
d RIGHT STRAP F

Figure 22/ Responses During Double-Lane Change

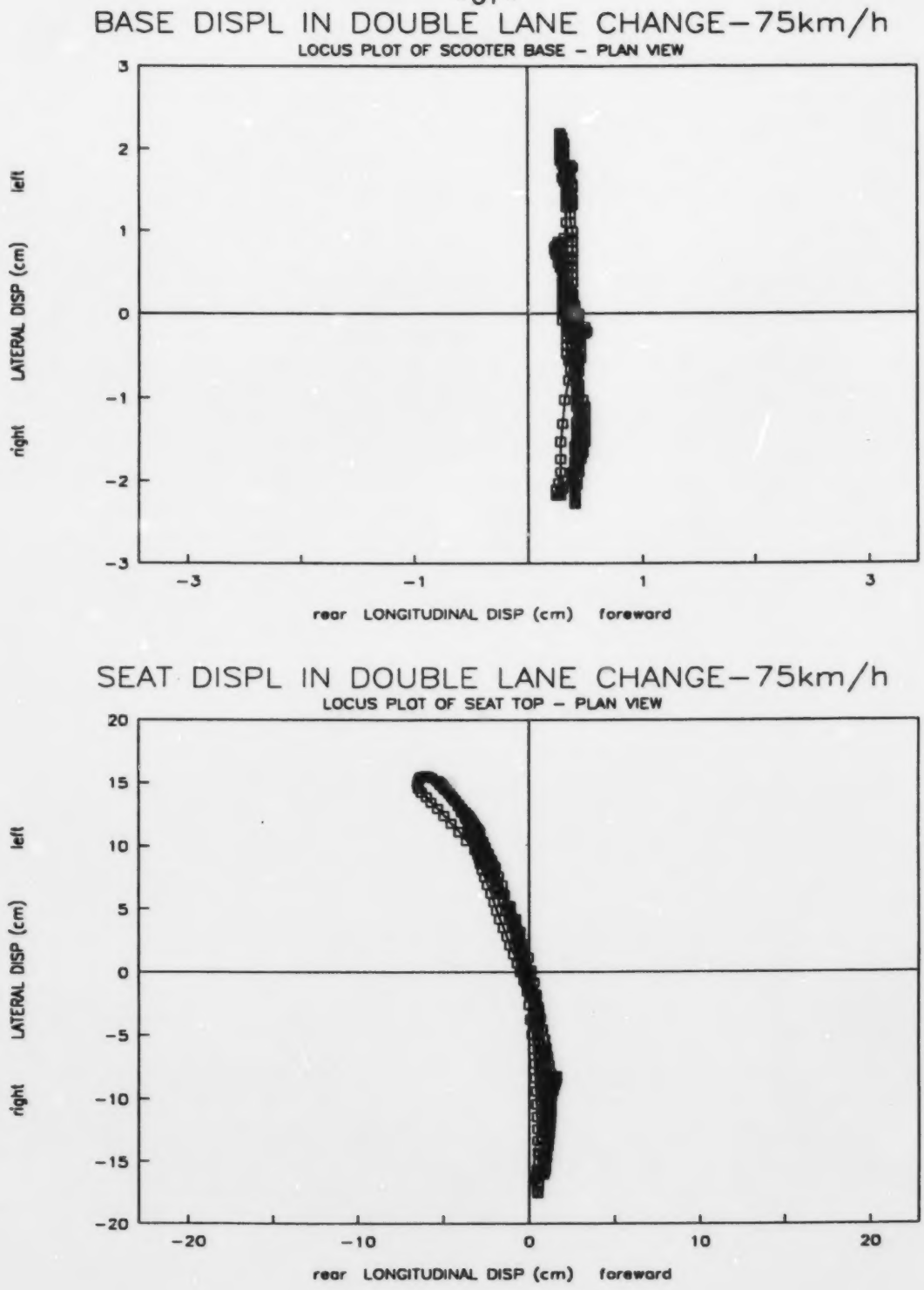


Figure 23/ Scooter Loci During Double-Lane Change

Figures 20 and 21. Figure 22 shows a close correlation between the responses of the scooter and the input lateral acceleration. The rear tie-down tensions are relatively symmetrical about the zero line, indicating that the load sharing is relatively balanced.

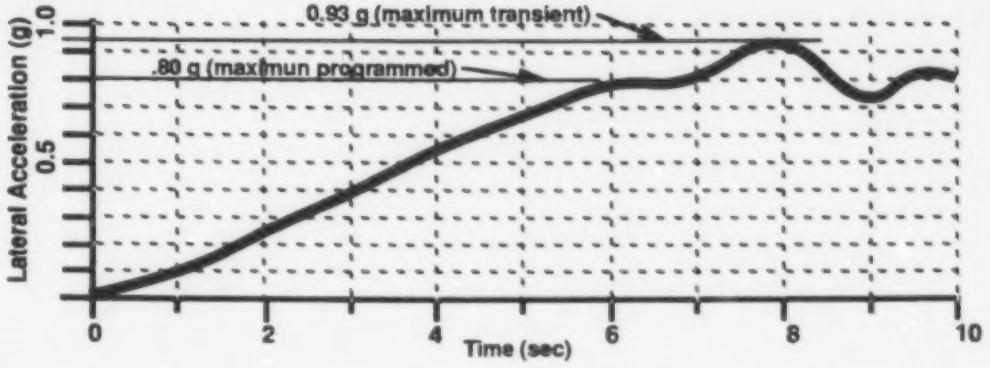
The plots of Figures 23 are loci of the scooter base and seat back respectively. The base shows only lateral motion, with an amplitude of about 2 cm, and without any longitudinal coupling. The upper seat however shows a distinctive trace due to the coupling influence of the shoulder strap on the dummy. This constrained a rearward motion as the scooter rolled left, which was absent in a right roll. The excursions were in the range 15 cm to the right to 18 cm to the left. As with other tests, the scooter remained relatively secure to the vehicle floor, while the seat and the dummy moved substantially. This was the most violent of all tests performed, with some lateral acceleration peaks in the range 0.8-0.95 g.

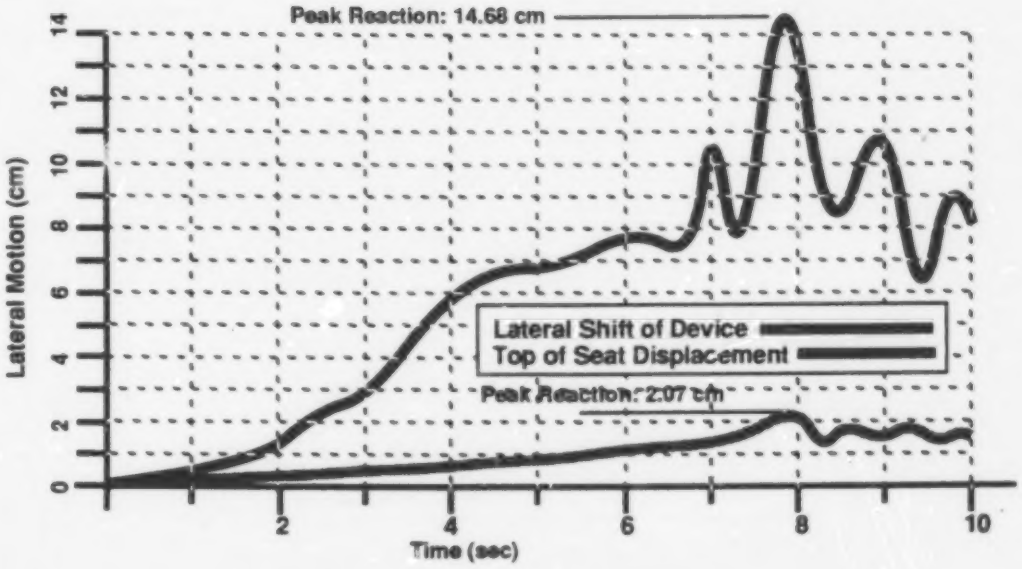
6.5/ Spiral Turn

In the spiral turn to the right, the vehicle experiences a progressively increasing lateral acceleration to the left. The rate of increase is dependent on the speed through the course. The lowest speed was 45 km/h, the highest 60 km/h. The typical lateral acceleration, for a 60 km/h run, is shown in Figure 24. The portion up 0.8 g is the spiral, or programmed portion, the balance is overshoot and corrections made to keep the vehicle on the constant radius sector of the course. This portion has attendant oscillation brought on by tire slide and rotation of the vehicle in the yaw and roll planes. The lateral motion of the scooter is also shown in Figure 24. The maximum lateral displacement of the base occurred after the spiral, with movement up to 2.07 cm. The maximum top of seat displacement occurred in the same area, peaking at 14.68 cm. The displacement of the scooter during the spiral was linear with acceleration, and showed little erratic or oscillatory motion during this phase. The oscillatory portion, after the spiral, was due to vehicle sliding in this zone. Data from test runs are shown in Figure 25, plotted against lateral acceleration. These plots only show the lateral acceleration on the spiral and not the constant radius sector. The plots of lateral acceleration and displacement appear linear and progressive.

6.6/ Constant Radius Turn

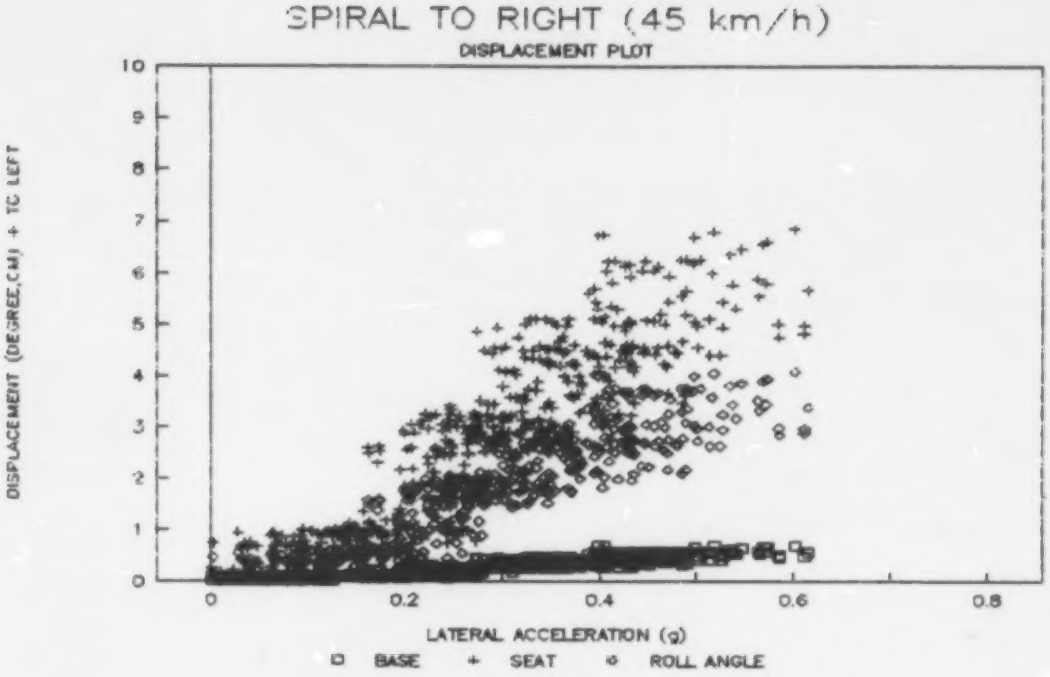
This test is a unidirectional version of the D409 constant radius turn, conducted to a higher speed and hence greater lateral acceleration. It was conducted for three different cases: the nominal, with a scooter tire pressure of 245 kPa (35 psi) and tie-downs secured per manufacturer's recommendations; with scooter tire pressure reduced to 105 kPa (15 psi) and tie-downs secured per manufacturer's recommendations; and with scooter tire pressure reduced to 105 kPa (15 psi) and tie-downs secured with a low tension of 0.12 kN. The results, shown in Figures 26 and 27 for all three conditions, represent steady state responses. It can be seen that the plots are reasonably linear and progressive in all cases.





Roll Angle Achieved at Maximum Programmed Lateral Acceleration = 4.35°
Roll Angle Achieved at Peak Lateral Acceleration= 8.37°
Right Q-Straint Load Increase=0.55 kN
Left Q-Straint Load Decrease=0.49 kN

**Figure 24/ Spiral Turn-
Shift, Roll, and Load Displacements**



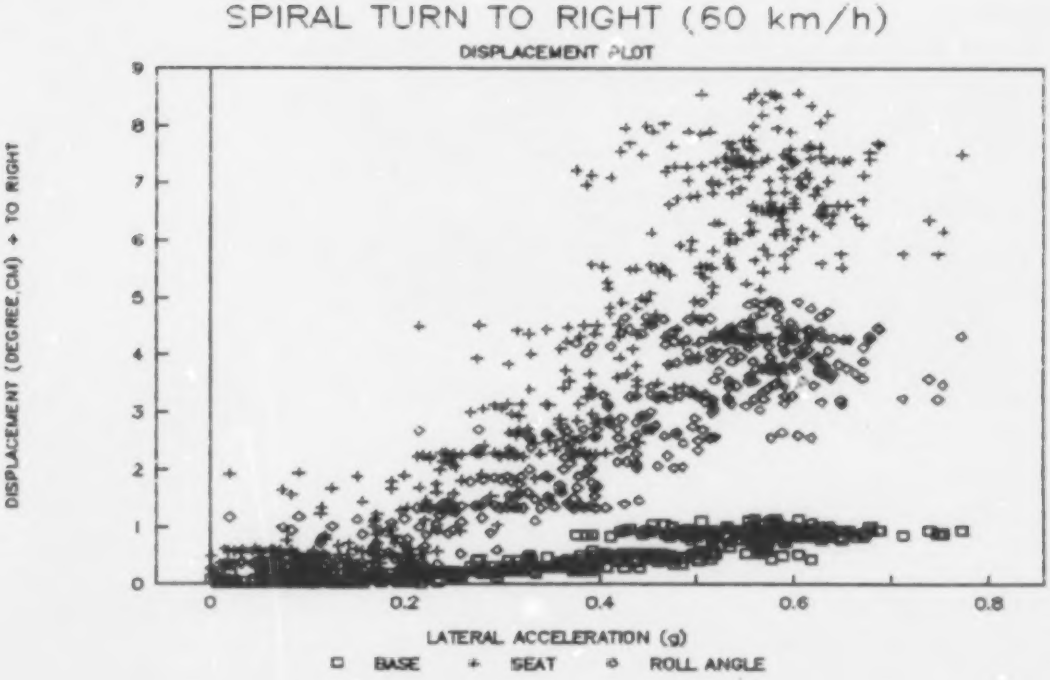
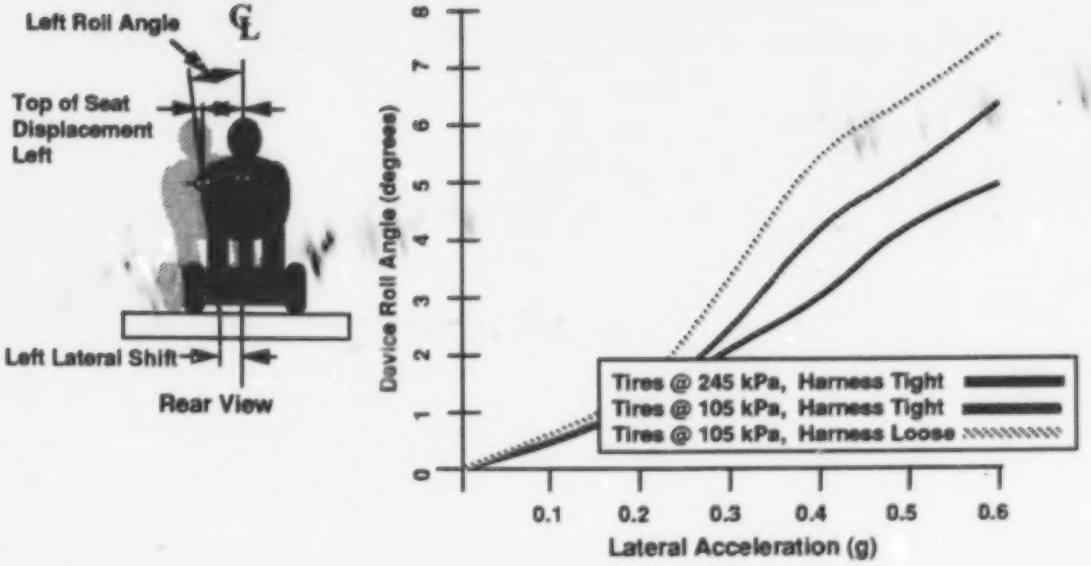
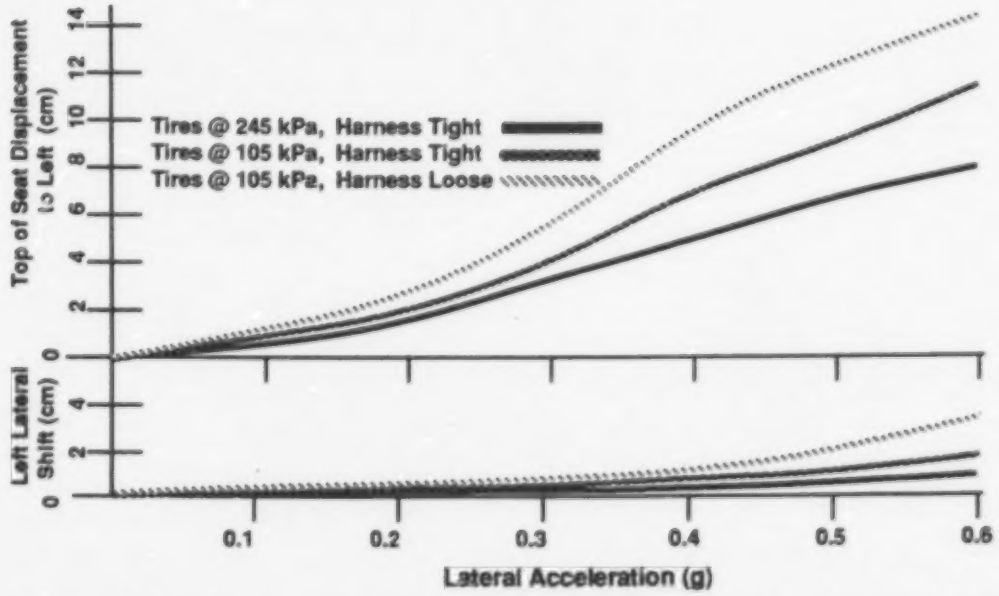


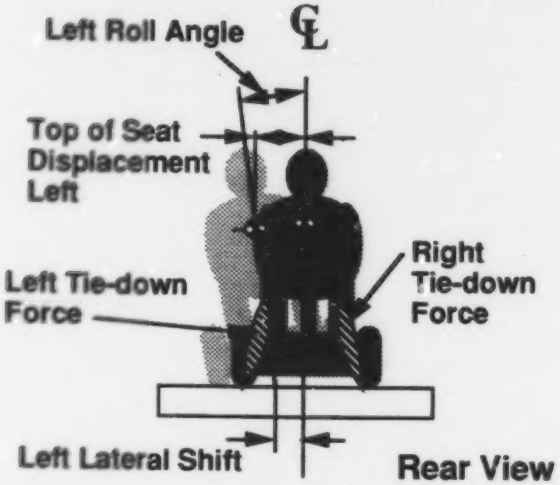
Figure 25/ Spiral Turns

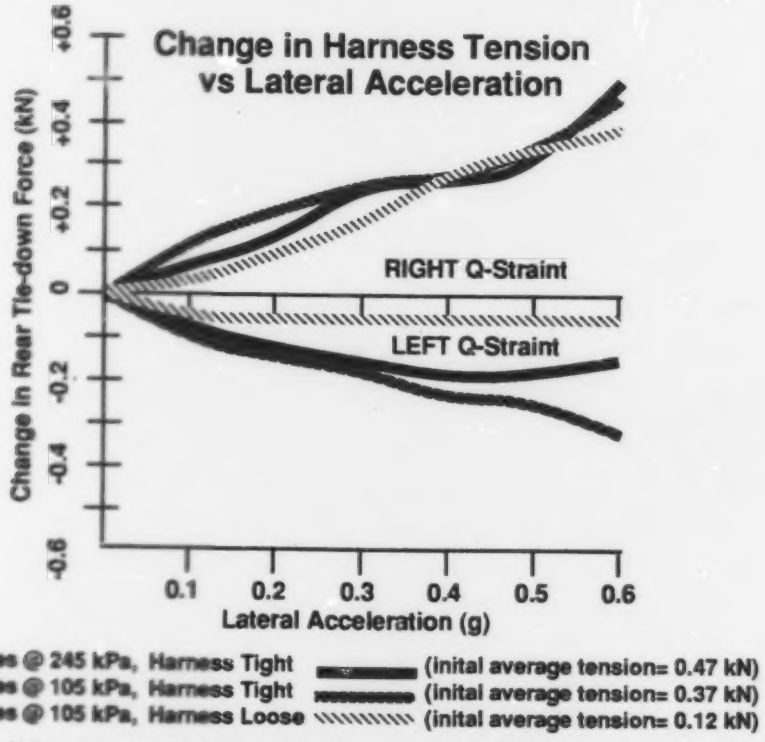




Outer Wheel traversing a 15.24 m radius turn at various speeds, clockwise direction

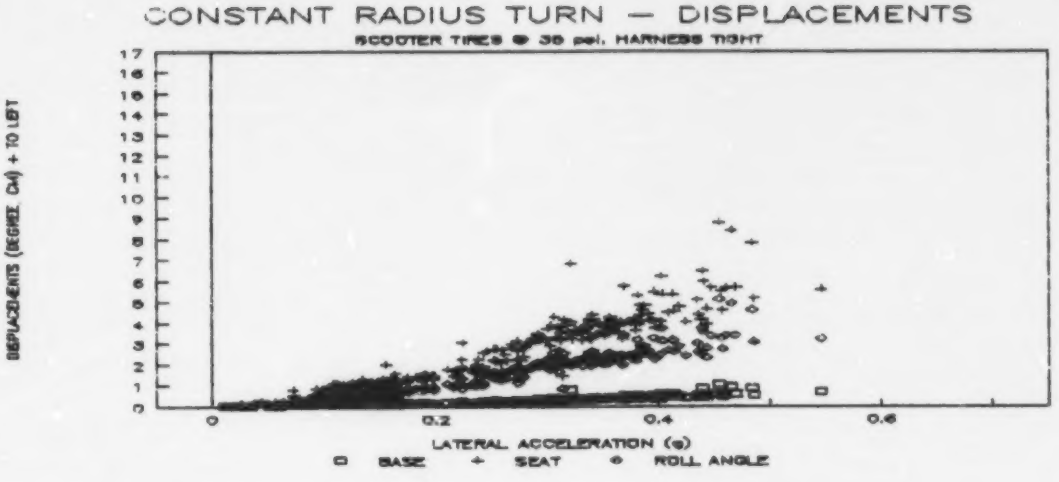
**Figure 26/ Constant Radius Turn-
Shift and Roll Displacements**

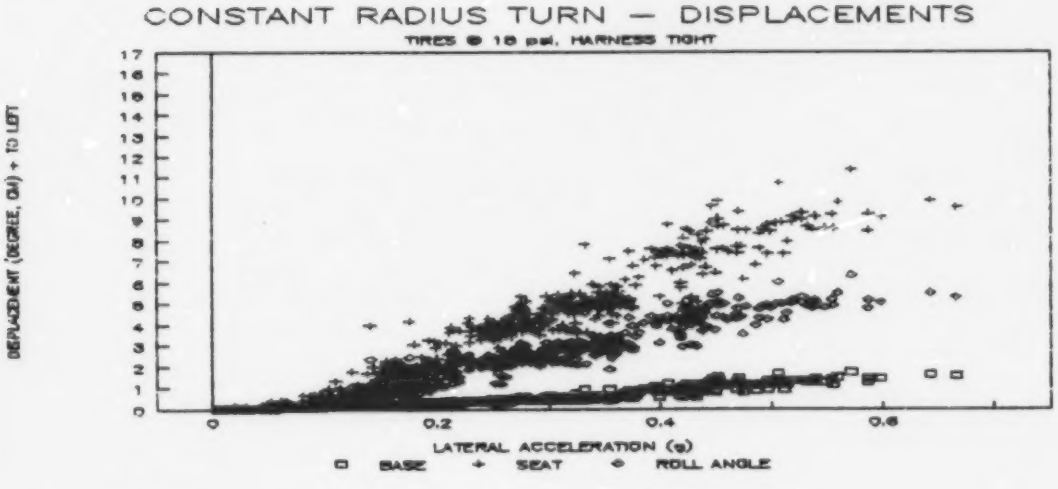




Outer Wheel traversing a 15.24 m radius turn at various speeds, clockwise direction

**Figure 27/ Constant Radius Turn-
Change in Harness Tie-down Forces**





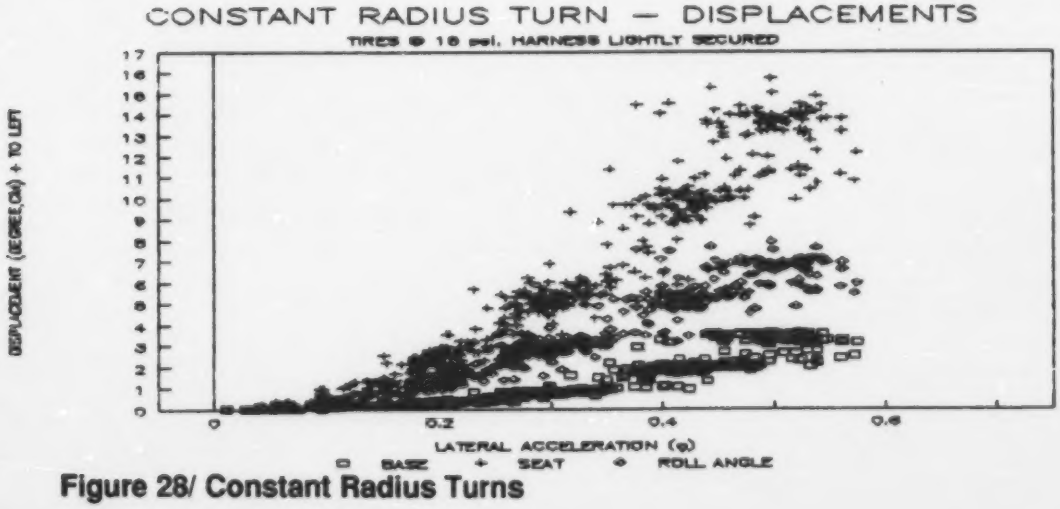


Figure 28/ Constant Radius Turns

Data from three test runs, one for each case, are shown in Figure 28. The density of the data for the nominal condition indicates a relatively well secured scooter with little base displacement. When scooter tire pressure or tie-down tension is reduced, the responses remain reasonably linear and progressive, although showing greater magnitudes than the nominal case. The reduced tire pressure reduces the vertical stiffness of the tires and hence allows greater roll and lateral displacement. The density of the data with reduced tire pressure still indicates a relatively well secured scooter, but with a decreased stiffness. The density of the data scatter with reduced tire pressure and reduced restraint tension is somewhat greater than the previous tests with better restraint, indicating a loosely secured scooter with a decreased stiffness and perhaps some hysteresis effect due to slackness of the straps.

6.7/ J-Turn

The J-turn provides a very rapid lateral acceleration to the vehicle. This was done in both right and left directions. Figure 29 shows the vehicle input and responses of the scooter. The lateral acceleration averaged 0.75 g, and was reached in about 0.75 seconds. The lateral shift of the scooter base was about one cm and remained offset by approximately 0.25 cm after the manoeuvre was completed. The top of seat displacement was 8.75 cm for the right turn and 5.44 cm for the left turn, which is attributed to the asymmetrical lateral retention property of the shoulder harness, with corresponding differences in roll angle. Displacement data from a test run are shown for left and right turns in Figure 30, plotted against lateral acceleration. The turn to the left shows the influence of the shoulder harness in restraining lateral movement, in the way that the curves tend to flatten out for lateral acceleration above 0.3 g. This restraint does not appear in the right turn, where the motion appeared to be linear and progressive, and for the most part the scooter returned very close to its original position.

6.8/ Abrupt Braking

In this test the vehicle is stopped by means of a violent sustained brake application from 80 km/h until a full stop is achieved. The general average deceleration plot is shown in Figure 31. Since the displacement was in a forward direction, the combination of lap belt, rear tie-down, and shoulder strap absorbed the forces and therefore allowed very little motion. The forward motion of the seat was 1.90 cm, and of the base was 0.8 cm for a deceleration of 0.77g. The rear tie-downs increased tension by approximately 0.6 kN each, during the deceleration. Upon stopping, the scooter experienced pitching on its own tires, augmented by pitching of the vehicle on its own suspension. This oscillation took several seconds to subside fully. Data from a test run are shown in Figure 32. The greatest pitch angle of the scooter was only 0.7°, a very low angle for such a large deceleration.

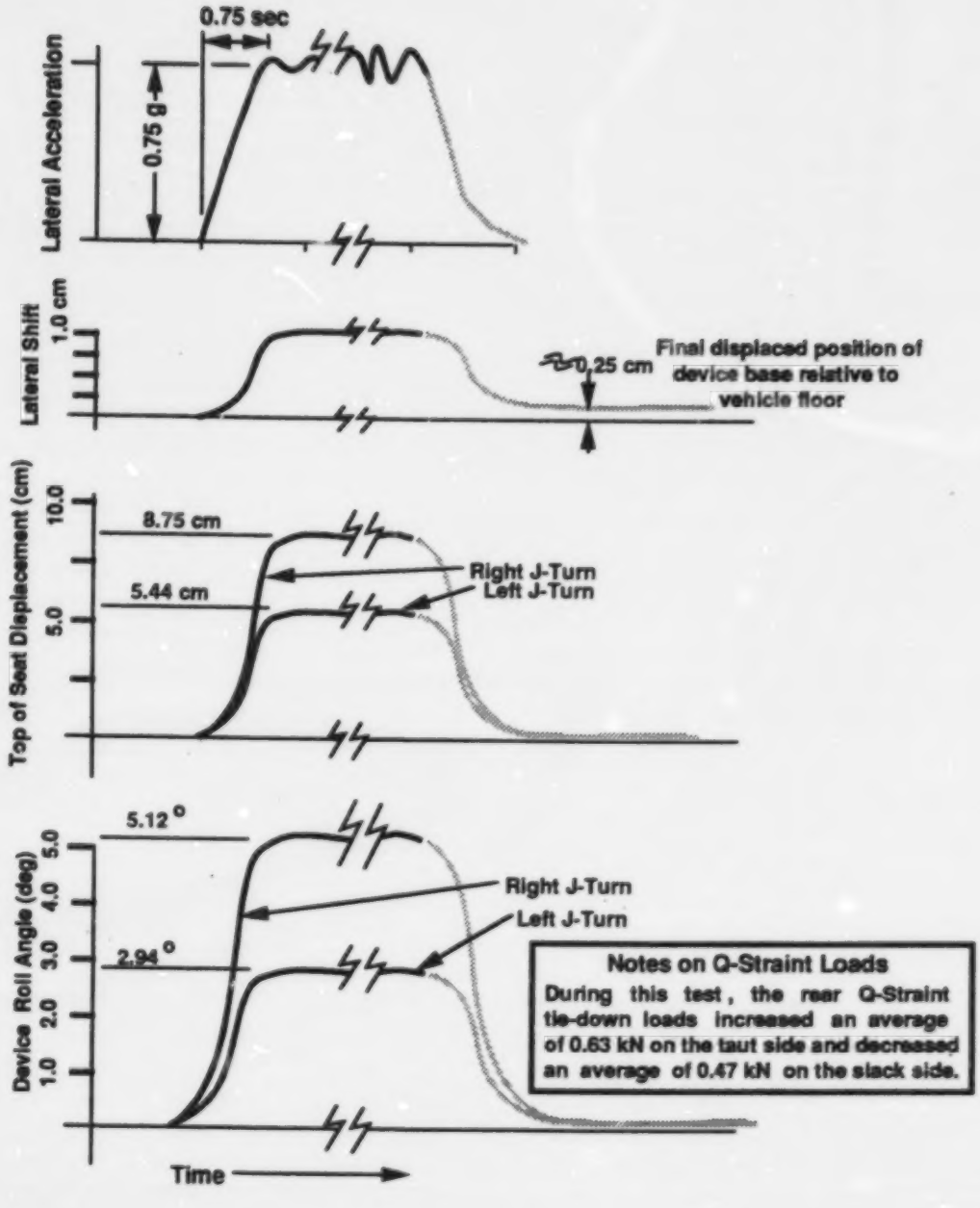


Figure 29/ J-Turn-
Shift, Roll, and Load Displacements

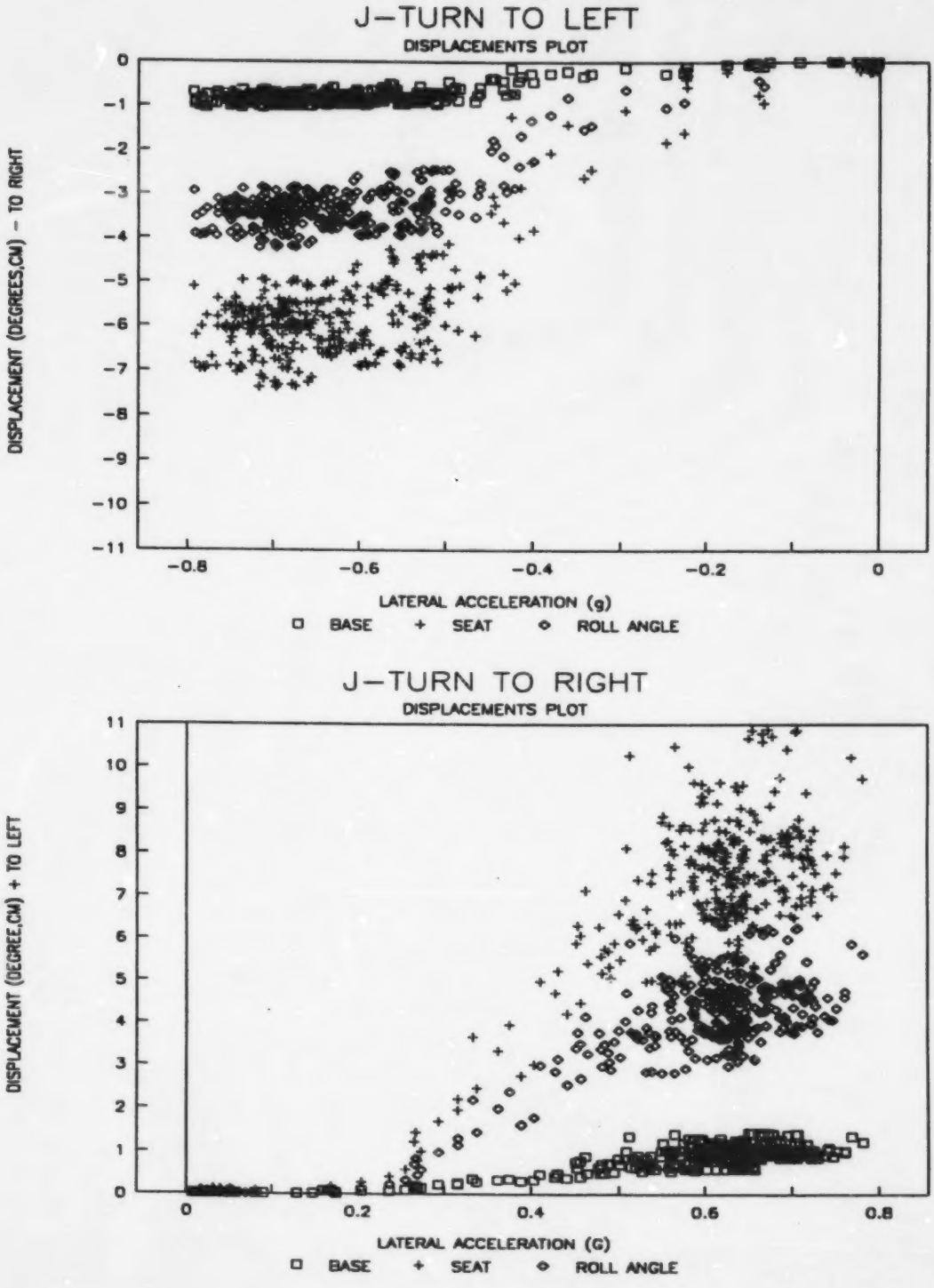
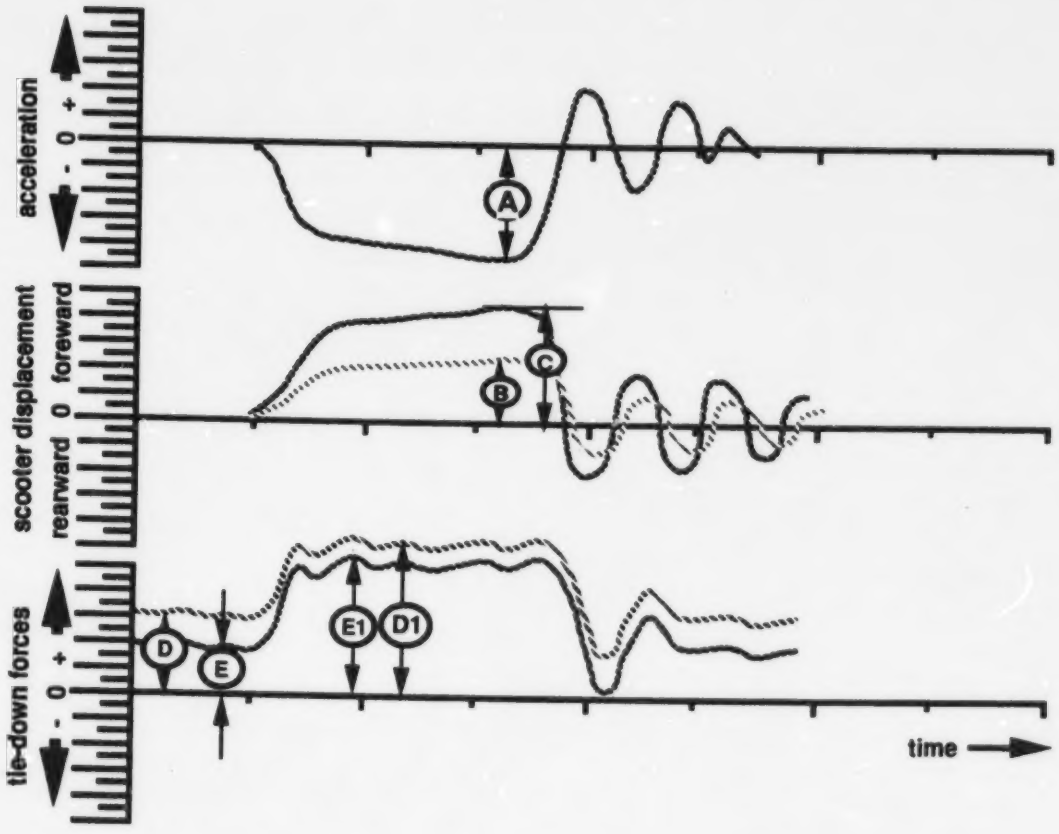


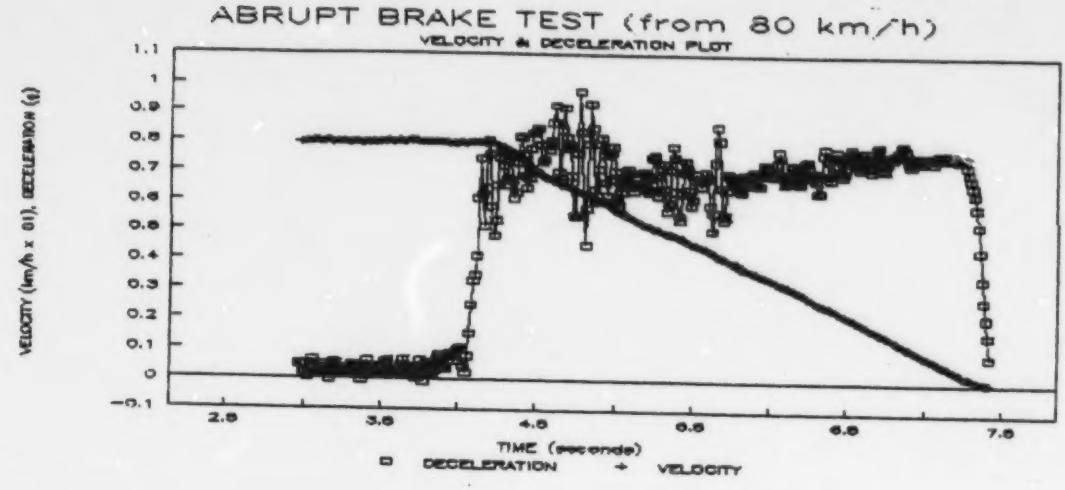
Figure 30/ J-turns

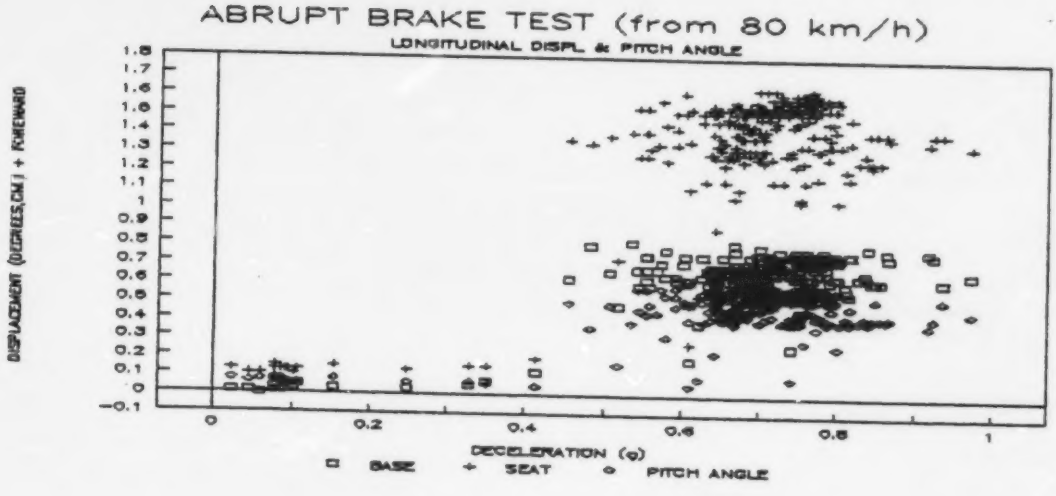


The following average results are based on a maximum performance deceleration from 80 km/h to full stop, two runs.

A - Maximum Longitudinal Deceleration	0.77 g
B - Scooter base maximum displacement	0.80 cm
C - Scooter seat maximum displacement	1.90 cm
D - Initial Left Tie-down Load	0.37 kN
D1- Maximum Left Tie-down Load	1.10 kN
E - Initial Right Tie-down Load	0.43 kN
E1- Maximum Right Tie-down Load	1.05 kN
Maximum Scooter Pitch Angle	0.7 °

Figure 31/ Abrupt Braking





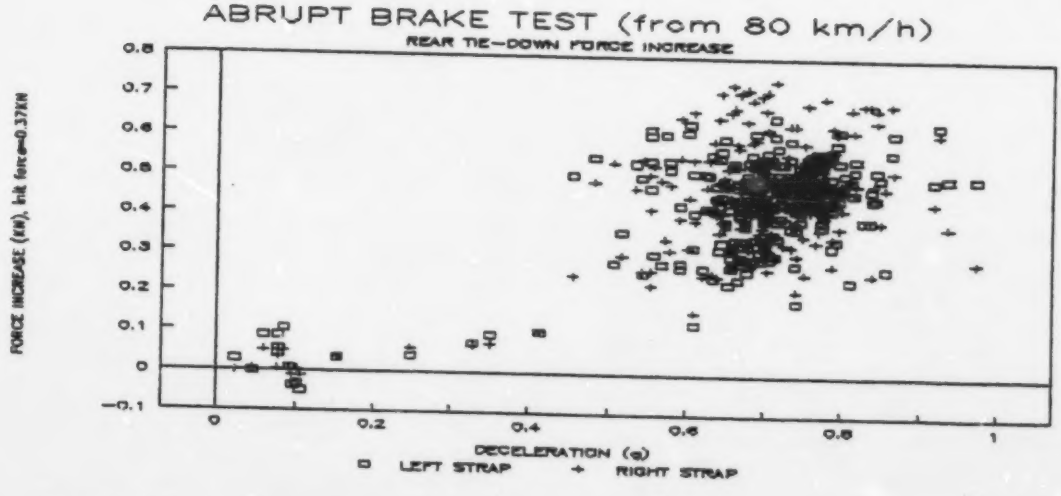
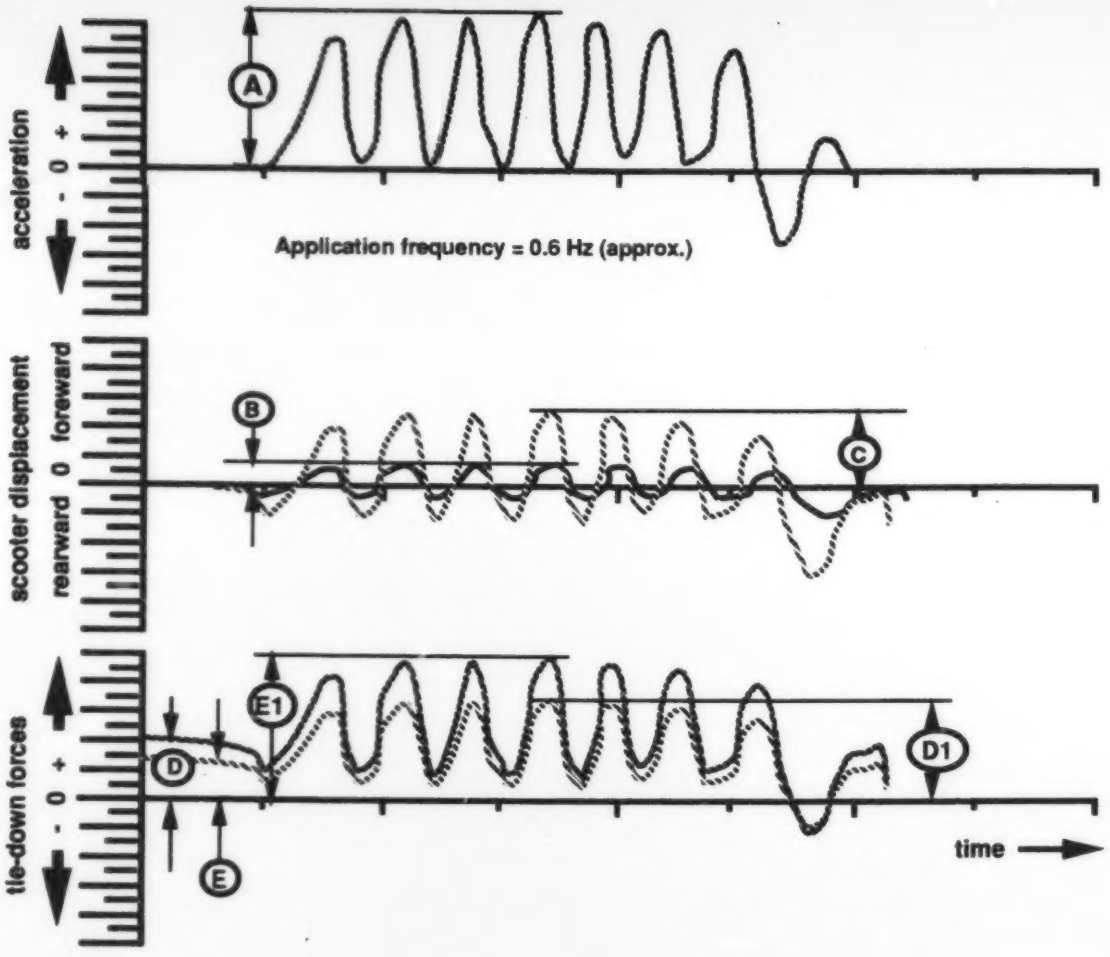


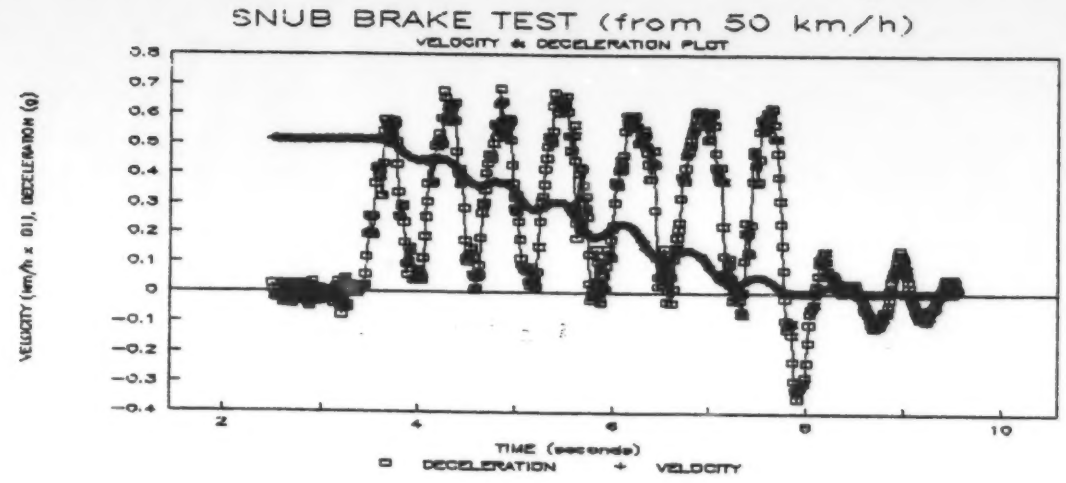
Figure 32/ Abrupt Braking

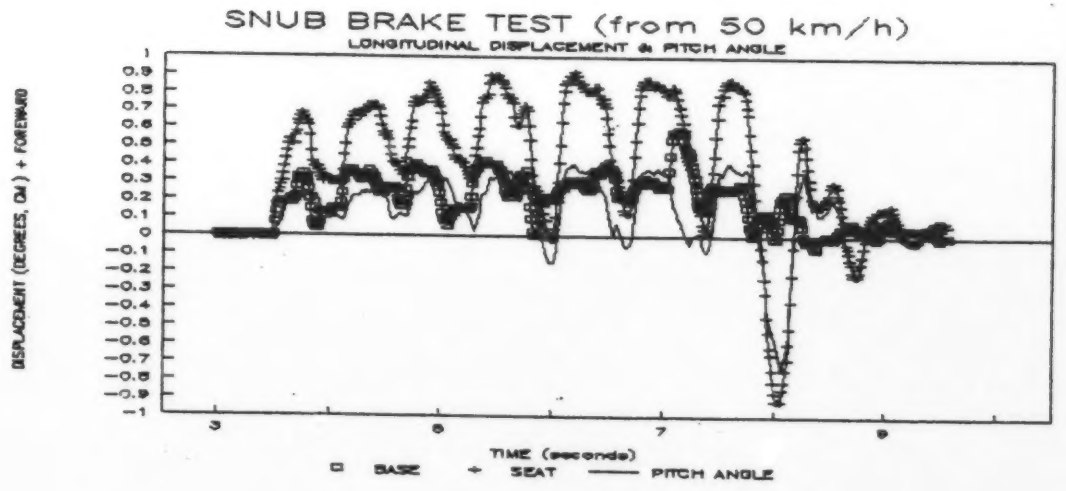


The following average results are based on an intermittent brake application from 50 km/h to full stop with seven applications at an approximate frequency of 0.6 Hz.

A - Maximum Longitudinal Deceleration	**0.57 g**
B - Scooter base maximum displacement	**0.48 cm**
C - Scooter seat maximum displacement	**0.94 cm**
D - Initial Left Tie-down Load	**0.84 kN**
D1- Maximum Left Tie-down Load	**1.15 kN**
E - Initial Right Tie-down Load	**0.87 kN**
E1- Maximum Right Tie-down Load	**1.33 kN**
Maximum Scooter Pitch Angle	**0.3 °**

Figure 33/ Snub Braking





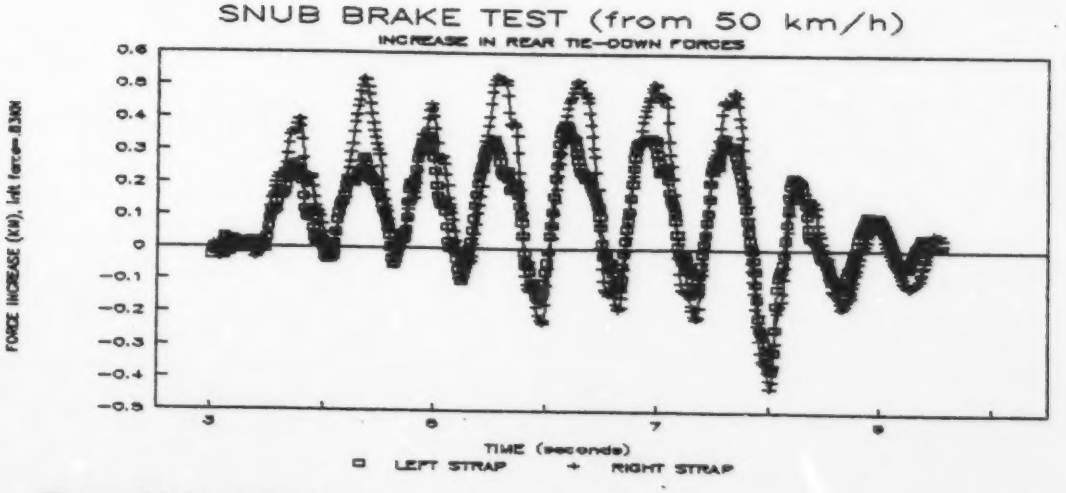


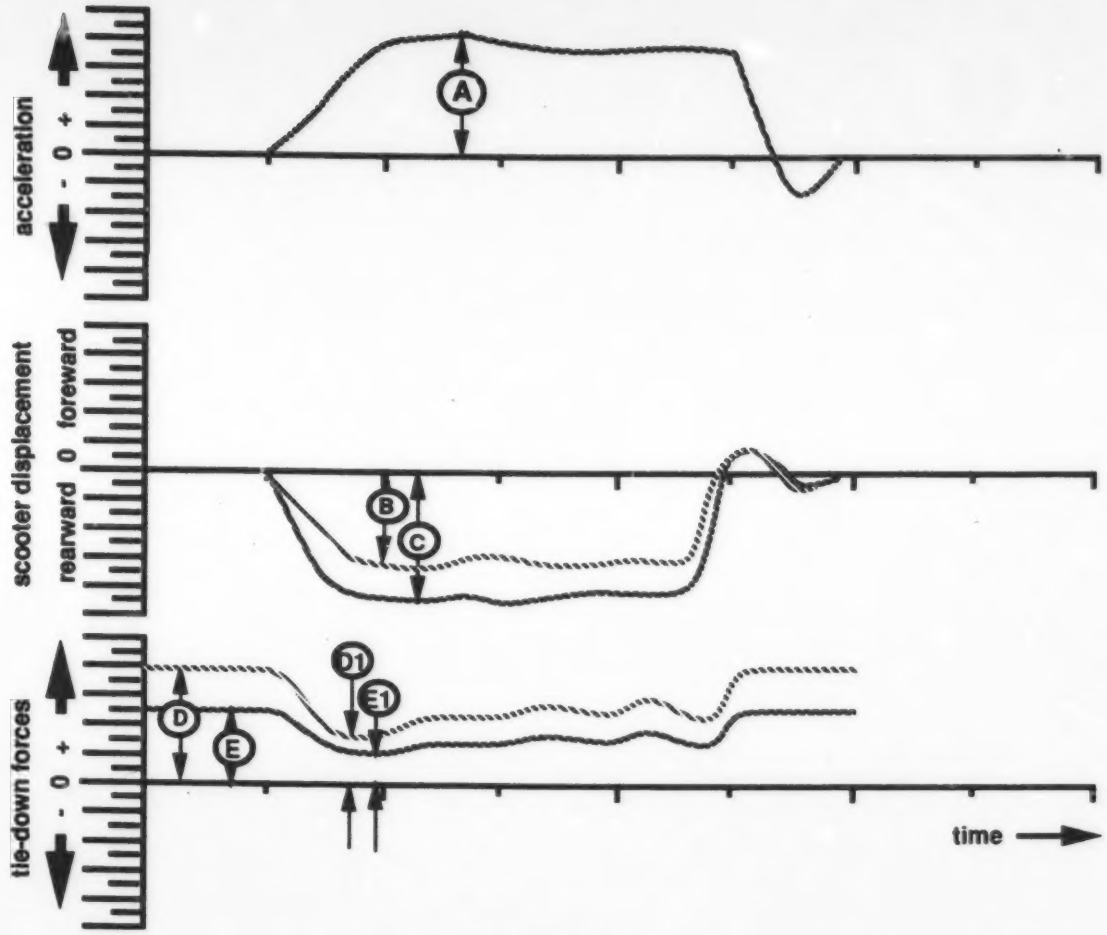
Figure 34/ Snub Braking

6.9/ Snub Braking

This test used a pulsating application of the brake pedal which caused the vehicle to pitch during the deceleration phase, thus causing a pitch in the scooter. The results are summarized in Figure 33. The average peak acceleration was 0.57 g, and theapplication frequency was about 0.6 Hz. The base moved 0.48 cm, the seat top moved 0.94 cm, and the tie-down loads increased approximately 0.4 kN in an oscillating manner reflecting the actual brake applications. The scooter and rider appeared well restrained during this test and did not exhibit a high pitch amplitude that would be deemed excessive. Time histories of data from a test run are shown in Figure 34.

6.10/ Back-up Braking

This test result is similar to the D409 acceleration test, but with a larger acceleration. The results are summarized in Figure 35. The base moved rearward 0.33 cm while the seat moved 1.55 cm for an acceleration of 0.71 g. This movement is in excess of that experienced in the abrupt braking test, primarily because the lap belt and shoulder harness do not restrain the dummy in the rearward direction. Data from a test run are shown in Figure 36. The relationship between acceleration and top of seat displacement shows a close correlation. The displacements and pitch angle are seen to be relatively linear with longitudinal acceleration, with some levelling off at the higher accelerations. This may be due to compliance in the seat post, and bushings bottoming, thus transferring the load to the scooter frame. The rear tie-down forces also show a close correlation with longitudinal acceleration.



The following average results are based on maximum performance braking while vehicle is travelling in reverse at low speed, two runs.

A - Maximum Longitudinal Acceleration	0.71 g
B - Scooter base maximum displacement	0.30 cm
C - Scooter seat maximum displacement	1.55 cm
D - Initial Left Tie-down Load	0.79 kN
D1- Minimum Left Tie-down Load	0.44 kN
E - Initial Right Tie-down Load	0.79 kN
E1- Minimum Right Tie-down Load	0.44 kN
Maximum Scooter Pitch Angle	0.8 ^{o}

Figure 35/ Back-up Braking

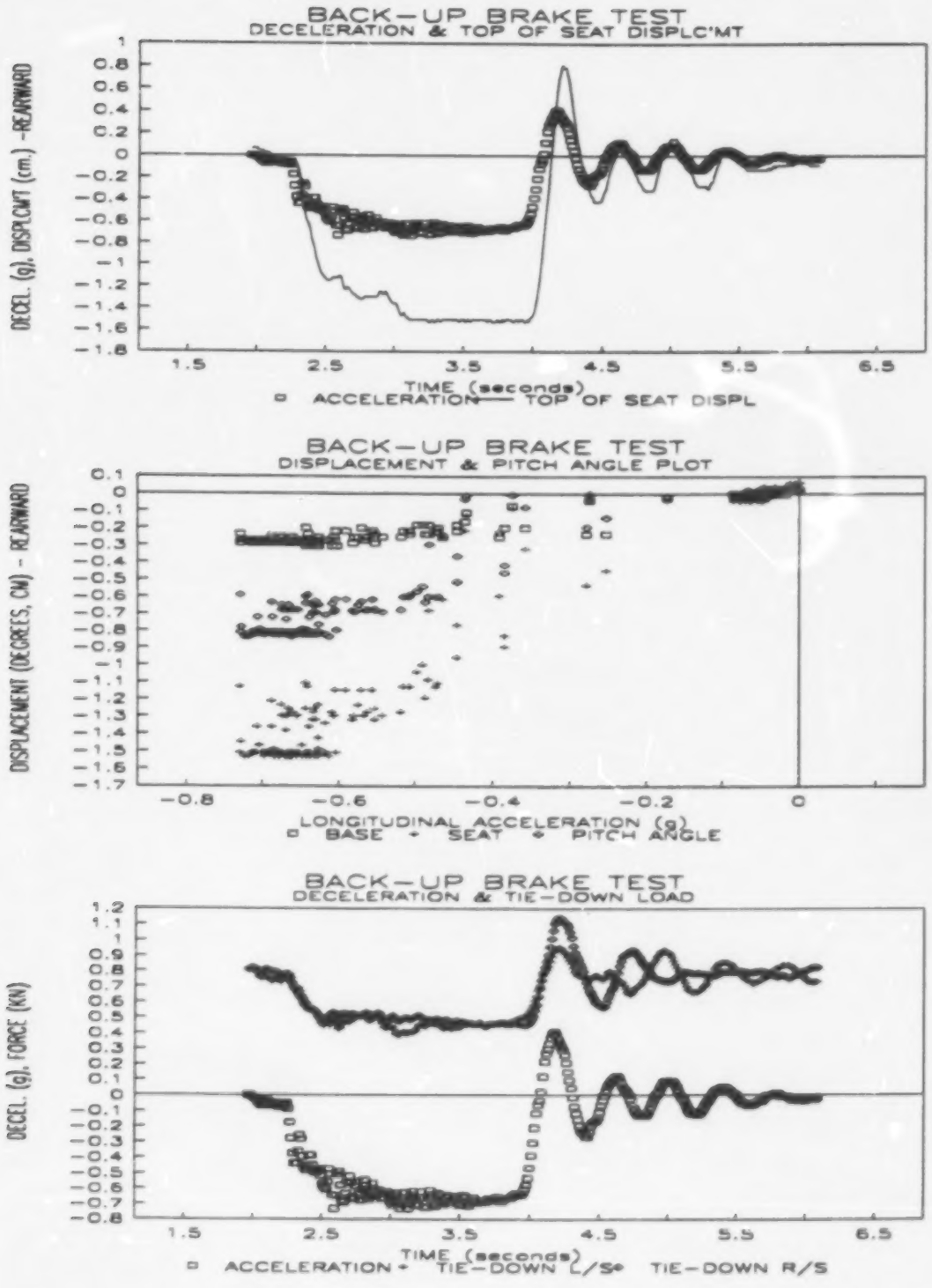


Figure 36/ Back-up Braking

7/ DISCUSSION

Lateral displacements were the largest detected during this test. The longitudinal motions in the braking tests were small by comparison to lateral motion. The abruptness and nature of the severe lateral loading tests produced seat displacements of up to 18 cm, corresponding to a scooter roll angle of about 10°. Although measurements were not taken on the dummy, calculation reveals that the motion at the dummy's head would be in excess of 25 cm. The tests did not appear to compromise or jeopardize the integrity of any of the equipment under observation. The dummy was properly restrained at all times, and returned (with the scooter) close to its original position after each run. The dummy's head did come very close to the inner wall of the vehicle on several occasions, but there is no record of any contact.

For the purposes of this test, the dummy's wrists were taped to the armrests of the scooter. This was to simulate the rider grasping the armrests to support the upper body. The result was that part of the inertial load of the dummy was transferred to the scooter through a somewhat natural mechanism. It was noted that the seat post assembly of the scooter flexed considerably, due to deflections within sleeves and bushings and deflections of attachment points. The scooter manufacturer recommended securement of the Q-Straint to this portion of the scooter. When the rear restraint tie-downs were secured, the seat post deflections became obvious. The front securement point, on the other hand, was a loop attached directly to the frame near the front axle, which appeared more robust. The loads sensed by the rear tie-down transducers were only a portion of the total longitudinal force generated by the scooter. The shoulder harness was secured directly to the upper rear door jamb and also carried part of the longitudinal force. It was not instrumented.

Scooter base movement was actually measured to the scooter structure, whereas D409 requires measurement at the tire to floor contact point. The latter could not be accomplished to any degree of accuracy due to the distortion of the pneumatic tires under loading. While comments have been made on the base movement results with respect to the context of D409, they must nevertheless be treated with the appropriate consideration. The current movement format of D409 may not be appropriate for scooters with quite flexible pneumatic tires.

The three D409 tests revealed very little scooter movement, either at the base or at the seat back, as shown in Figure 37. The scooter seat is unrestricted in the acceleration mode and since accelerations are quite low, compared to braking decelerations, movement was minimal. The braking version of the D409 test yielded the largest deceleration, but motion of the scooter was arrested by the rear tie-downs, lap belt, and shoulder harness. The lateral loading D409 test showed larger movements toward the left as a result of the restraining mechanism of the shoulder harness. The movements in each case were higher than those allowed under D409 for the chair base, as seen in Figure 37.

The severe lateral input tests, the J-turn, constant radius turn and spiral turn, all produced a lateral response of about 8° of scooter roll per g of lateral acceleration. The dynamics of the scooter suspension and its tie-down in the double lane change produced an amplification to 12° per g. In almost all cases, the response was linear and the system reacted in a predictable manner. A summary of scooter lateral excursions during these tests is shown in Figure 38.

The scooter was well restrained in the braking tests and did not appear to pitch or displace excessively. In almost all cases the scooter returned to its original position. The movement of the dummy was not recorded and motion of the head or neck was not captured.

It appeared from the testing that the scooter itself was relatively rigid, apart from the seat attachment discussed above. The scooter roll angle, seat and dummy head displacement appeared as a result of tire vertical stiffness, and not as a result of flexure or compliance within the framework of the scooter itself. Some of the lateral shift of the scooter was as a result of tire lateral deflection relative to the axle. This was more predominant with lower scooter tire air pressures. The roll angle and lateral displacement were sensitive to the air pressure in the scooter's tires, and the tension applied to the tie-down system. Large changes in roll and lateral displacement could be made by adjustment of these variables as shown in Figure 39. The bulk of the testing was done using the manufacturer's recommended value for air pressure in the scooter's tires, and the recommended tight cinching of the rear tie-downs. In practice, it is probable that many scooter owners will check and adjust tire pressures quite infrequently. Much of the time, therefore, the pressures will be less than the manufacturer's recommended value, as indeed they were on the unit used for this test when it was delivered. It was not possible to apply much greater tie-down tension than that used for this test. In practice, therefore, somewhat lower tension may be the norm. The nominal case used for this test is therefore likely to provide an upper bound on scooter roll resistance. It might be advisable to consider whether a standard should address some condition less than the manufacturer's recommended values.

Several of the manoeuvres conducted in this test brought the vehicle close to the limits of its stability. This type of testing is potentially hazardous. It should only be conducted on a proper test facility, with a professional driver who understands the limits of the vehicle, and knows how to recover from an emergency. Proper safety equipment and procedures are mandatory. All manoeuvres that will approach the limits of stability must be made in a progressive manner, increasing speed or aggressiveness in small increments. Proper instrumentation is necessary for the test staff to judge objectively whether it is safe to proceed to the next increment.

The linearity of responses allows a valid severe driving standard to be created, if necessary. There is room to set it at a level above the current D409 standard, but still adequately below the limits of stability of typical vehicles that the safety precautions used by MTO in these tests are not required.

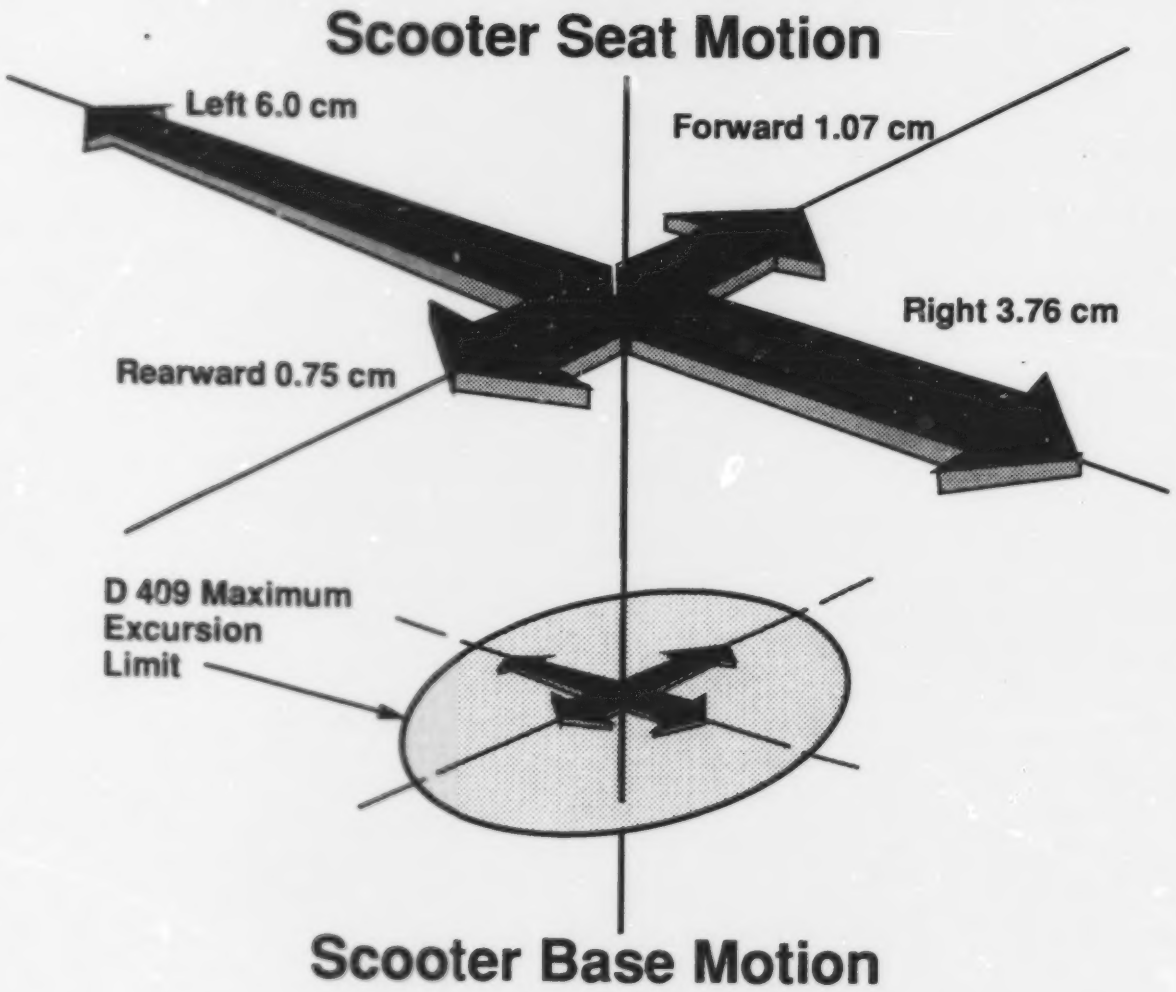


Figure 37/ Scooter Seat Motion
- D409 Tests

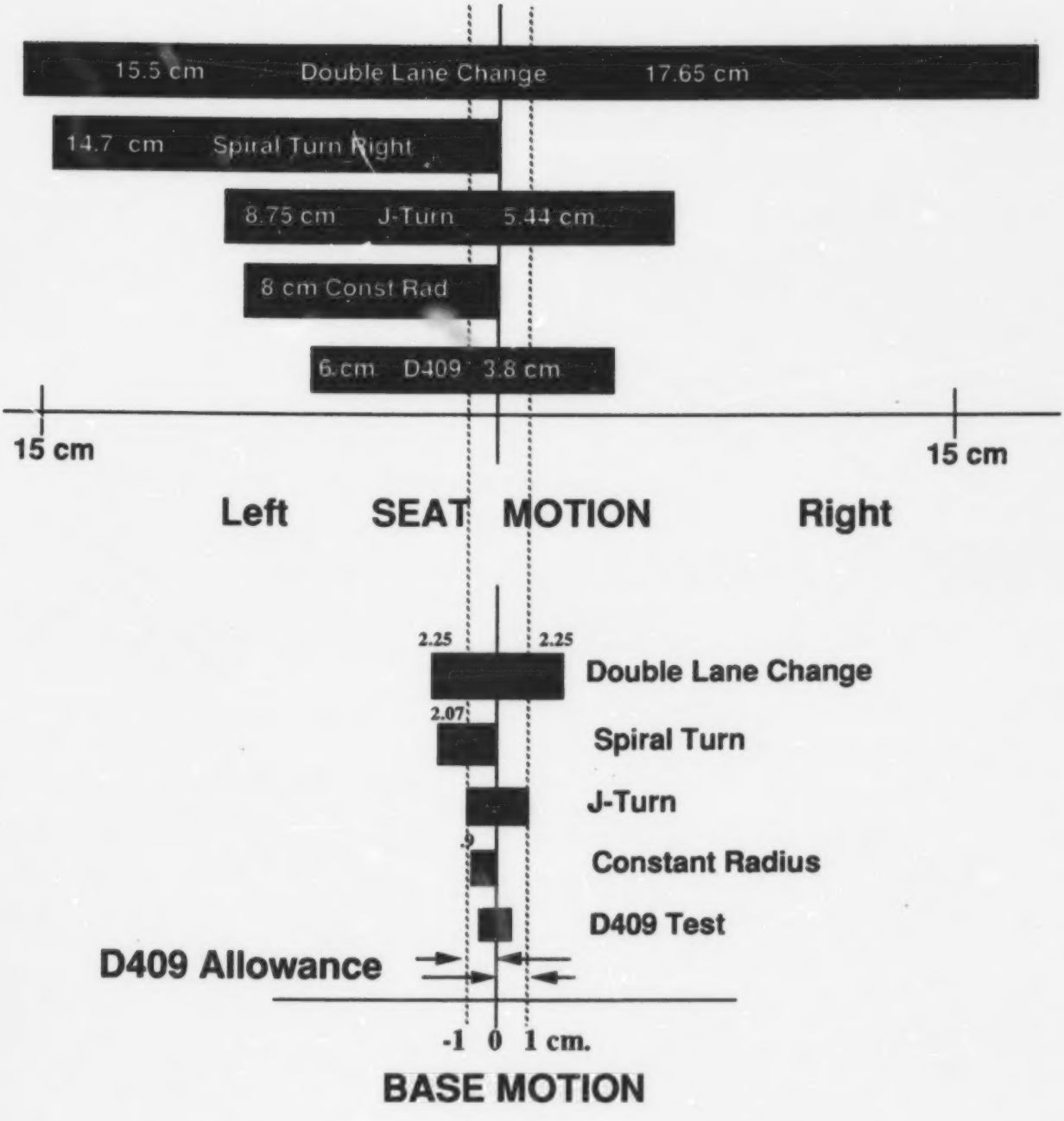


Figure 38/ Scooter Lateral Motion - Severe Driving Test

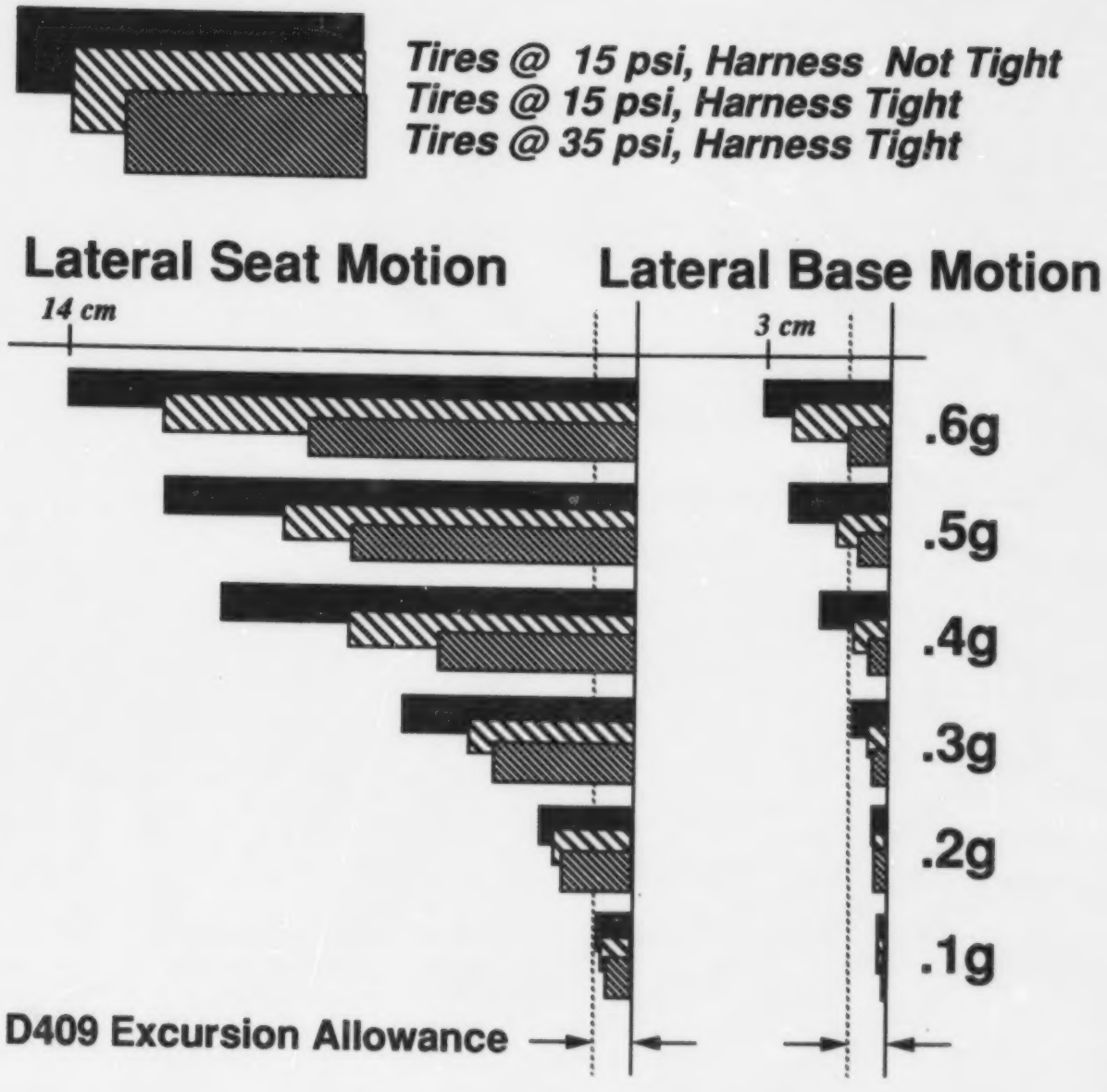


Figure 39/ Effect of Tire Pressure & Harness Tension on Motion

8/ CONCLUSIONS

An exploratory test of a typical scooter, with a seated rider and a typical tie-down system has been conducted. It used the tests specified in Canadian Standards Association Standard CAN3-D409-M84, and other lateral and longitudinal manoeuvres that provided a range of types of input up to the limits of stability of the vehicle.

In all tests, the rider was fully restrained, and the scooter and rider returned close to their original positions.

The base of the scooter stayed within D409 limits when subjected to the three D409 wheelchair tests. The upper portion of the scooter moved within a motion envelope 9.7 cm wide and 1.8 cm long. While the scooter base technically met the letter of D409, it might be questioned whether the scooter's large roll motion is desirable.

During severe driving tests, the base of the scooter moved up to 2.25 cm laterally, and the upper portion of the seat moved up to 18 cm laterally, from an initial upright position. Longitudinal displacement was minor. The upper portion of the scooter and the dummy swayed large amounts under lateral loads, and the dummy came very close to the inner wall of the vehicle at various times. The frequency and amplitude of the swaying motion might, in the long-term, give rise to complaints by seated riders about the ride quality of the vehicle, even though it is almost entirely due to the characteristics of the scooter.

The roll angle and displacement were very sensitive to scooter tire pressure and tie-down preload. A combination of these two variables, within the bounds of this test, almost doubled the roll and displacement response of the scooter. The advisability of using realistic, rather than manufacturer's recommendations, for values in a standard might be considered.

The displacement of the scooter when secured to manufacturer's recommendations, was linear and proportional to acceleration in both longitudinal and lateral planes.

The relatively narrow track and flexibility of the scooter's tires appeared to be the largest contributing factor to scooter roll and seat displacement. This could probably be reduced very significantly if a structural member of the scooter rested on a rigid spacer that lifted the scooter's rear wheels clear of the floor, perhaps a more elaborate tie-down arrangement. The tie-down mechanism restraining, longitudinal motion appeared adequate. This is likely due to the scooter wheelbase, longitudinal plane tie-down angle (triangulation), and placement of the shoulder harness anchor. The shoulder harness appeared tc play an essential role in the stability of the rider in both lateral and longitudinal manoeuvres. If an inertia reel could be used, it would reduce any temptation for riders to slacken this important part of the restraint for greater comfort.

It does appear possible that a valid, severe driving standard could be defined, if required, at a level above the current D409 standard, yet still below the limits of stability of the vehicle.

A video film has been produced that visually documents the findings presented in this report.